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A Feasibility Demonstration of an Aerial Surveillance Spill Prevention System

U.S. ENVIRONMENTAL PROTECTION AGENCY

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A FEASIBILITY DEMONSTRATION OF AN AERIAL SURVEILLANCE SPILL PREVENTION SYSTEM

by

Robin I. Welch
Allan D. Marmelstein
Paul M. Maughan

Project Officer
John Riley

for the

OFFICE OF RESEARCH AND MONITORING

ENVIRONMENTAL PROTECTION AGENCY

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ABSTRACT

Acquisition and interpretation of multispectral aerial photography and thermal infrared imagery were performed to evaluate their utility in an aerial surveillance spill prevention system. The San Francisco Bay area was used as a test site; major sub-areas were delineated which contained facilities and activities that might lead to spills of oil and other hazardous substances into waterways.

Results demonstrated that high quality, small scale (1/40,000 to 1/60,000), color infrared photography can be used for regional surveillance, leading to classification of land use into areas where potential spill sources exist. High quality, large scale (1/5,000 to 1/10,000), color aerial photography can be used for localized delineation of potential spill sources. Localized surveillance should be supported by low angle, oblique telephotography and limited ground surveillance.

Recommendations are given for an operational spill surveillance system using multiscale aerial photography obtained on a 9-inch film format. Use of thermal infrared imagery is not indicated at this time, as additional information acquired is minimal compared to resources required for its acquisition.

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FIGURES (cont.)

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SECTION I

CONCLUSIONS

The feasibility demonstration completed by Earth Satellite Corporation for the Environmental Protection Agency has shown conclusively that remote sensing techniques can be used to delineate areas where oil and other potentially hazardous materials are processed, stored, and transported. Furthermore, these techniques can also be used for determining where protective devices exist, where they should exist if they do not, and where lack of sufficient protective measures has resulted in previous spill problems.

An aerial surveillance system developed for spill prevention purposes should incorporate the following:

- Small scale (1/40,000 to 1/60,000) color infrared/Wratten 12 aerial photography for regional analysis in order to delineate oil refineries and other industrial installations which are potential sources of pollutants.

- Large scale (1/5,000 to 1/10,000) color aerial photography of probable high hazard areas as determined by interpretation of the small scale photography to provide detailed information on specific spill threats as well as active spill sources.

Table 1 further specifies the use of small and large scale photography. Large scale color photography was demonstrated to be extremely versatile in the identification of various types of installations and activities which have potential as spill sources. Furthermore, such photography is extremely useful for pinpointing existing protective features, as well as installations which should be protected or in which protective facilities have been compromised.

At the present time it has not been demonstrated that the use of thermal infrared imagery will produce information on potential spill sources which cannot be obtained by aerial photography with less cost and in a more versatile manner.

It is important to note that a multiplicity of camera systems is routinely available which can satisfy the specific demands of an aerial surveillance system. However, routinely available thermal scanners show a wide variability in both thermal and spatial resolution, whereas the data developed as a part of this project indicate that resolution demands for thermal data are high.

In order for an aerial surveillance system to be most useful, careful, comprehensive photointerpretation must be performed. Therefore, the necessity exists to either train technicians in photointerpretation or to employ qualified interpreters to perform comprehensive image analysis.

Table 1. Recommended Surveillance System.

	Low Altitude, Large Scale: High Industrial Concentration	Low Altitude, Large Scale: Low Industrial Concentration	High Altitude, Small Scale: High Industrial Concentration	High Altitude, Small Scale: Low Industrial Concentration
Scale	1/5,000	1/10,000	1/40,000	1/60,000
Film	Aerial Color (Kodak SO-397 or equivalent)		Color Infrared (Kodak 2443 or equivalent)	
Filter	Wratten 1A or Haze		Wratten 12	
Camera*	9" x 9" format, roll film magazine with 200 ft. film capacity			
Lens*	8-1/4" focal length, high resolution		6" focal length, high resolution	

*For oblique (hand-held) photography: 70mm format, roll film magazine with 15 ft. capacity, availability of 80mm, 150mm, and 250mm focal length lenses, as required.

Furthermore, the use of photointerpretation keys developed specifically for use in interpreting photography for spill prevention will provide important guidelines for image interpreters assigned the task of detecting and identifying potential spill sources.

SECTION II

RECOMMENDATIONS

Recommendations stemming from this project for an operational aerial surveillance system are grouped into two major classes:

- Flight Planning and Data Acquisition
  Includes the selection of flight lines; coordination of aerial data acquisition with ground truth acquisition; selection of sensors, films, and filters; specifications of flight parameters to include altitude, time of day and season; cost analysis; and logistic support.

- Interpretation and Data Analysis
  Includes the methods and equipment for interpretation and mensuration of imagery; interpretation and use of collateral data; use of interpretation aids; and presentation of results in a usable format.

Flight Planning and Data Acquisition

General Considerations

Following initial selection of areas for reconnaissance, the flight path of the photographic aircraft must be determined in order that desired coverage be obtained. Flight lines should be plotted on topographic maps of a scale commensurate with size of the area to be covered and complexity of the flight line. U. S. Geological Survey (USGS) 7-1/2 minute quadrangles (1/24,000 scale) or 15 minute quadrangles (1/48,000 or 1/62,500 scale) are generally used for flight line plots. These maps usually indicate, by shading and symbols, the location of industrial areas. However, boundaries and placement of individual structures within these industrial areas must be considered only approximate and cannot be relied on in mission planning. At the time of mission planning a current aeronautical chart for the area to be flown should be consulted to determine if restrictions exist pertaining to aircraft flights over the target area.

Relevant ground truth can be a valuable aid to the image interpreter. Whenever possible, ground truth acquisition should follow large scale overflights in close succession to optimize correlation of information from these two sources. Obviously, the more dynamic the phenomena, the greater the importance of performing ground observations soon after photointerpretation. Ground observation should be designed to verify photointerpretation findings on specific spill threats and to determine exactly the identity and condition of features and facilities that appear to be a potential threat or a source of past spill that has not been properly corrected.

Color photographs taken on ground visits to target areas and low angle, oblique color transparencies in 35mm or 70mm format are very useful graphic aids to the image interpreter. Ground and oblique photography should be acquired under the direction of an interpreter who has been working with the vertical imagery. Although interpretation of vertical imagery alone by a skilled interpreter can yield an abundance of data, the availability of ground truth data and oblique and ground photography from previous studies will decrease both cost and time of the interpretation.

In areas of denied access, low altitude oblique telephotography may best fulfill the need for ground truth. A recommended supplemental source of intelligence on such an area would be visits to similar facilities employing the same materials and processes.

Aerial color reversal film appears to be of the greatest general application in hazardous material surveys. There are advantages to interpreting original positive color transparencies, because of the near-natural color rendition and high resolution of color films. Both black-and-white infrared and panchromatic films ordinarily used in aerial reconnaissance are usually reproduced as opaque positive prints or are copied on film as positive transparencies for interpretation purposes because of the special skill necessary to interpret negatives. On black-and-white photography, pollutants in or out of water are harder to identify, in that they are rendered in shades of gray rather than in near-natural color.

The use of color photography for aerial surveillance and reconnaissance projects is becoming more common for the following reasons:

- The information content of color film is usually higher than that of black-and-white for many applications, due in part to high color fidelity and the wide variety of interpretative methods which can be used on positive transparencies.

- The quality of color films has improved greatly in recent years, and there is presently a greater latitude of acceptable exposure, thus making them easier to use.

- Color aerial films are being used by more commercial aerial survey firms, thereby insuring a more certain and steady supply.

- Although higher cost of color imagery has long been presented as a drawback, the additional cost is usually only a small part of the overall project cost, and the purchase of color photography is justifiable by increased data accuracy and output. Color photography can often be flown at smaller scales than panchromatic photography and still provide the same information.

For the above stated reasons, it is recommended that conventional aerial color film be used for acquiring aerial photographs at medium and low altitudes (below 20,000 feet) for an aerial surveillance spill prevention system. Over industrial areas, the haze-penetrating characteristics of color infrared film (when exposed through a Wratten 12 filter) and its enhancement of the land/water interface make it the best choice for small scale photography when such photography is to be acquired at altitudes above 20,000 feet.

A number of high quality cameras, designed or adaptable to aerial use, can be used with the specified film/filter combinations. The camera recommended for a spill prevention system is a 9-inch format mapping camera with lens focal length appropriate for the scale desired and the operating ceiling of the aircraft.

As will become apparent, the critical relevant parameters evaluated were film/filter and scale, rather than format. Format merely affects area coverage per frame at any given scale; hence, recommendations relative to format were inferred from the nature of the problem and from an evaluation of the effects of area coverage on the working format. In some instances, for example where a need for vertical photography over a small area exists, some other format may be the most appropriate choice; nonetheless, in the general case, it is felt that a 9-inch format system will be of greatest utility. The rationale for recommending the 9-inch format includes the following considerations:

- Image acquisition cost is decreased with large format imagery, due to reduction in the number of photographs necessary to cover any given area, since, at constant scale, area coverage per frame increases with format size. Thus, at any given scale, 70mm format covers only 6% of the area covered by 9-inch format.

- Both interpretation and mensuration of the aerial imagery is enhanced by displacement of the image away from the vertical aspect. With increasing format size this radial displacement also increases, presenting, in effect, a slightly oblique view of objects imaged on the outer one-third of each frame. At least one method of height determination is simplified by considerable radial displacement. With successive frames and overlapping flight lines, one achieves both the vertical and oblique view of the object.

- Large format size enables the interpreter to more accurately analyze the effect of topography on target areas. Within a reasonable range for topographic analysis, area coverage is of more importance to the interpreter than is scale.

- Nearly all commercial aerial photographic companies have 9-inch format camera systems, whereas few have 70mm systems.

- Generally, 9-inch format camera systems provide annotation between frames of date, altitude, frame number, and, in some cases, other ancillary data. Such between-frame annotation is not provided in 70mm systems.

For oblique photography from a light aircraft, the camera should be of high quality, light weight, and compact design, have interchangeable lenses, and be of about 70mm format. A number of cameras which meet these criteria, such as Hasselblad or Bronica, are readily available. A camera of this type, rather than a 9-inch format mapping camera, may be used in a vertical mode, although area coverage will be decreased, necessitating either reduced coverage or more flight lines.

The tendency of long focal length lenses to decrease vertical exaggeration or "flatten" images leads to a recommendation of the use of short focal length lenses and low flight altitude rather than long focal length lenses and high flight altitude. Lens focal length and camera configuration recommendations are presented in the following paragraphs.

Regional Vertical Coverage

Regional surveillance is that which will be used to classify land use activities and permit an interpreter to develop information which can be used to assign priorities to follow-up, detailed coverage. The information to be derived from regional analysis includes:

- Land use category to a 10-acre minimum size
- Number of storage tanks
- Major leaks on land and in water, or spill stains (300 feet in diameter or greater)
- Sources of waste products
- Major outfall discharge points
- Surface drainage patterns
- Water boundaries
- Dispersion of drainage in waterways
- Ship-loading facilities
- Major surface pipeline routes

These items are considered to be strategic data in that they usually need to be obtained only at infrequent intervals (annually or longer, depending upon needs and enforcement capabilities); hence, the stipulation that such coverage is best obtained when atmospheric conditions are, at the least, near optimum. Optimum conditions here refer to periods of no cloud cover and very light to no haze.

The system specifications for regional surveillance are as follows:

- Vehicle
  - -- Fixed-wing aircraft
  - -- Single or multi-engine with turbo chargers or jet engines
  - -- Camera hatch in fuselage
  - -- Precision navigation instruments (as specified for instrument flight rules by the Federal Aviation Agency)
  - -- Electrical system and mounting arrangement to accommodate an aerial camera
  - -- Service ceiling, 25,000 feet

- Camera
  - -- High resolution aerial camera with removable film magazine such as Wild RC-8 or equivalent
  - -- 9-inch format
  - -- 6-inch focal length

- Film/Filter Combination
  - -- Kodak Aerochrome Infrared Type 2443 or equivalent (color infrared with Wratten 12 filter)

- Film Processing
  - -- Kodak RT Color Processor, Model 1411 or as specified by the film manufacturer

- Scale
  - -- 1/40,000 over areas with dense industrial development and characterized by persistent atmospheric haze
  - -- 1/60,000 over areas with scattered industrial development and generally minimal atmospheric haze

- Atmospheric and Sun Angle Restrictions
  - -- No cloud cover over target area
  - -- Light to medium haze or less
  - -- Sun angle above 30°

- Stereoscopic Overlap and Sidelap
  - -- 60% forward lap (55% to 65% acceptable)
  - -- 30% sidelap (10% to 50% acceptable)

- Angle of Coverage
  - -- Vertical coverage required with no more than 3° out of the vertical acceptable

Local Vertical Coverage

Local vertical coverage can be used to identify specific spill threats and assess the need for further follow-up by ground observation. The information to be derived from local analysis includes:

- Specific activities currently being carried on at each site
- Minor leaks on land and in water, or minor spill stains (10 feet diameter or greater)
- General identification of waste products
- Minor outfalls
- Status of drainage features (active or inactive)
- Pumping and regulating stations
- Surface pipeline routes
- Condition and integrity of dikes
- Drainage facilities associated with revetments around tanks and other facilities
- Condition and integrity of revetments
- Volume of lagoons or storage piles
- General conditions of pipelines and supporting structures
- Transshipment points
- General condition of storage tanks
- Presence or absence of protective features and the state of repair of each (e.g., rails, fences, railcar barricades, dams, floating booms, pilings, channel markers)
- Numbers and types of vehicles, vessels and railcars

Because of their transient or changing nature, many of these items are considered to be tactical data. Therefore, remote sensing designed to obtain these data usually must be accomplished at more frequent intervals, perhaps under less optimum weather conditions than specified for acquisition of strategic data.

The system specifications for obtaining detailed localized information are as follows:

- Vehicle
  - Fixed-wing aircraft
  - Single or multi-engine, reciprocating or turbo-prop type
  - Camera hatch in fuselage
  - Instrumented for visual flight rules (as specified by the Federal Aviation Agency)
  - Electrical system and mounting arrangement to accommodate an aerial camera
  - Service ceiling, 12,000 feet

- Camera
  - High resolution aerial camera with removable film magazine such as Zeiss RMK 21/23 or equivalent
  - 9-inch format
  - 8-1/4-inch format length

- Film/Filter Combination
  - Kodak Aerial Ektachrome Type SO-397 or equivalent
  - Suitable haze filter, such as Wratten 1A or HF-2, -3, or -4

- Film Processing
  - -- Kodak RT Color Processor, Model 1411 or as specified by film manufacturer

- Scale
  - -- 1/5,000 over areas with dense industrial development and numerous potential spill sources
  - -- 1/10,000 over areas with scattered industrial development and few potential spill sources (if in doubt, the larger scale should be specified)

- Atmospheric and Sun Angle Restrictions
  - -- No cloud cover over target area
  - -- Light to medium haze or better (this requirement may be modified depending upon urgency for large scale coverage and frequency of acceptable atmospheric conditions)
  - -- Sun angle above 30°

- Stereoscopic Overlap and Sidelap
  - -- 60% forward lap (55% to 65% acceptable)
  - -- 30% sidelap (10% to 50% acceptable)

- Angle of Coverage
  - -- Vertical coverage required with no more than 3° out of the vertical acceptable

Local Oblique Coverage

Oblique aerial photographs have been shown to be very useful for documenting specific problem features and to provide images of facilities which are difficult to evaluate in vertical views because of overhanging structures or vegetation. Low altitude stereoscopic coverage is used to identify features which are not easily recognizable or whose condition cannot be evaluated from the vertical view. However, oblique coverage is difficult to specify without prior knowledge of the target area.

Oblique photography should not be considered as an end in itself, but only as support for vertical coverage. Its most advantageous use is as a substitute for ground truth where low angle oblique telephotography is more practical than a ground visit. For example, if vertical surveillance suggests the presence of a small oil leak, low angle oblique photography using ultraviolet or plus-blue panchromatic photography, which has been shown to be useful in detection of thin oil films on water, may be indicated. In any case of oblique photography, complete documentation must be obtained, including date, altitude, location, angle of view, film/filter, etc.

Oblique photography can be obtained from the photographic aircraft following vertical coverage by use of a hand-held 70mm camera with eye-level viewfinder and appropriate lens (80mm, 150mm, or 250mm focal length, as required). Care must be exercized in obtaining oblique photography so as to take advantage of the correct angle of illumination, to position the aircraft in such a manner that the ground scene is not obstructed, and to insure that aircraft motion is compensated in making the exposure.

Image Acquisition Procedures

The flight crew should be carefully instructed to use the flight maps, flight parameters, and system specifications supplied by the photointerpreter in order to obtain coverage as required. It should also be the responsibility of the flight crew to determine whether the prevailing weather conditions are suitable for coverage over the areas scheduled.

Exposure settings for lens and shutter should be determined by reference to manufacturer's specifications, but modified as necessary for the prevailing atmospheric and illumination conditions.

Color film processing should be performed as soon as possible after exposure to reduce the effects of color balance shift which can result from prolonged delay after exposure, particularly where film is subjected to high temperature environments.

Interpretation and Data Analysis

An important first consideration in commencing an image interpretation effort is organization. The particular system used is not critical, as long as it is applicable to the user organization. Film should be labeled with acquisition data, logged in, and stored for easy retrieval. Systematic interpretation is necessary to ensure that all image areas are scanned and that specific areas are interpreted according to their individual priorities. All interpreters should use the same symbols, codes, and record-keeping procedures to facilitate data storage and retrieval.

The equipment and physical facilities needed for an image interpretation shop depend largely upon image quality and final product desired. While high-quality transparencies are best exploited with zoom-stereoscopic systems, no amount of magnification or optical resolution can compensate for poor quality transparencies. Likewise, for most uses, light tables need only be suitable in illumination qualities and comfortable for the interpreter. If paper prints are to be used, stereoscopes should be selected on the basis of format and desired magnification range.

All available collateral data sources should be made available to interpreters during the read-out process. Common sources of collateral data are publications, photointerpretation keys, comparative photographic coverage, and ground truth data. If ground or aerial photography in 35mm slide format has been acquired, both slides and viewing equipment should be readily available.

The amount and detail of photogrammetry depends on the existence of a need for ground-distance measurements. Measurement of heights of vertical or near vertical objects and length and width of horizontal objects is relatively simple if object boundaries are discrete and the interpreter has sufficient knowledge of the conditions under which the imagery was acquired. Such measurements should be easily obtainable using the recommended system; thus, capacities of storage tanks and vertically-walled revetments can easily be determined. However, measurement of the holding capacity of banked earth revetments, catchment basins, and other irregular features, as well as establishment of a datum from which to measure, requires a cartographic camera, ground survey support, special image preparation equipment, complex plotting instruments, and technical expertise. Although the recommended system can be used to determine where such measurements are required, additional aerial photography and ground support, as detailed previously, would be required. Costs associated with these additional measurements run $60 to $100 per frame; thus, care should be exercised in their use.

Simple mensuration as described can be performed on vertical imagery with a minimal inventory of equipment, including a photointerpreter's magnifier, seven power, with reticle graduated in thousandths of feet and five one-hundredths of millimeters; a photointerpreter's rule with a range of at least 6 inches or 15 centimeters, graduated in the above state increments; a parallax wedge for height determination; and a simple calculating device, preferably a photointerpreter's slide rule or circular rule. Accuracy of photogrammetric measurements will depend on the resolution of the imagery, the accuracy of collateral image data, and the skill and precision of the image interpreter.

SECTION III

INTRODUCTION

This report represents the results of an Environmental Protection Agency project to demonstrate the feasibility of utilizing state-of-the-art technology in remote sensing aerial reconnaissance for spill prevention surveillance. Specifically, the objective was to determine the extent to which aerial remote sensing systems might be used to detect potential sources of water pollution by oil and other hazardous materials. Hopefully, such prior identification would permit appropriate action to be taken to prevent these potential sources from becoming actual. Remote sensing aerial reconnaissance seemed, and has proven to be, an excellent choice for such surveillance, because many potential and actual pollution sources occur in highly industrialized areas where, for various reasons, ground access, hence source identification, is extremely difficult.

This project utilized multispectral photography and thermal imagery. Many other remote sensing devices are available, but their highly specialized capabilities are not presently applicable to a project of this nature; such devices include magnetometers, radiometers, scatterometers, spectrometers, and others, some of which may ultimately be of use in spill surveillance.

For this initial demonstration project, the highly industrialized but geographically and culturally-varied San Francisco Bay area was chosen as the test site. Within this site, several target areas (later to be described) were selected which contained representative installations, in varied settings, of the type toward which a preventive surveillance effort might logically be directed.

The study was conducted in three phases. These phases, and a brief description of the tasks accomplished in each, were:

PHASE I: Preliminary Studies - A mid-altitude reconnaissance flight was made over the entire San Francisco Bay test site, thereby obtaining results which led to a flight plan for missions to obtain high altitude, small scale photography. This photography was obtained and interpreted to select the specific test areas for detailed study. A ground truth plan was also developed.

PHASE II: Program Implementation - An evaluation was made of various scales and sun angles, on the basis of which optimum values for each were selected. Low altitude, large scale photographic flights and day and night thermal infrared flights were planned and executed, as was ground truth coverage of all test areas.

PHASE III: <u>Data Analysis</u> - The large scale photography and thermal imagery was interpreted and correlated with ground truth. Photointerpretation keys were developed and a photo-interpretation test was administered to skilled interpreters The results obtained, and the conclusions drawn from them have led to recommendations for an operational aerial surveillance system.

SECTION IV

METHODS

Site Selection

The San Francisco Bay region was chosen as the test site because it represented geographically most of the situations wherein one might expect to find potential sources of oil and hazardous materials in juxtaposition to coastal and inland waterways.

Two methods were readily available for surveying the San Francisco Bay test site in order to identify specific candidate test areas: interpretation of existing photographs and aerial reconnaissance. Initially, a set of contact black-and-white scale (1/80,000) prints were purchased from open files of the U. S. Geological Survey. This stereoscopic coverage was interpreted in order to delineate areas of interest for further survey.

Within the San Francisco Bay test site, several sub-areas along the San Francisco Bay and Sacramento - San Joaquin River waterfront were overflown and delineated as candidate test areas for continued surveillance. From this reconnaissance flight, major sub-areas of the region were selected for high altitude overflight in order to obtain small scale photography for use in final selection of test areas. Selection of the test areas was coordinated with interpretation of recently acquired National Aeronautics and Space Administration (NASA) photography of the same region on the same type of film, but at a scale of 1/60,000 on a 9-inch format. This evaluation led to selection of test areas adjacent to waterways at Antioch, Pittsburg, Nichols, Avon, and Martinez, all on the south shore of the Sacramento River. On the San Francisco Bay shore, several additional large areas were chosen, including the waterfronts at Richmond, Oakland Estuary, and Hunters Point in the City of San Francisco (Figure 1).

Antioch (Figure 2)

The river waterfront at Antioch embodies several installations which are potential spill sources. Immediately adjacent to the waterfront is a paper and cardboard plant with a waste water outfall into a small slough. There is also a food canning plant on the waterfront, with direct outfalls into the river. Both installations are close enough to the waterfront that spills could occur during routine operations. Neither of the above-mentioned plants has any apparent protection against flooding or storm drainage.

Pittsburg (Figure 3)

The waterfront at Pittsburg contains numerous small industrial installations, as well as a very large steel mill. Situated on this waterfront

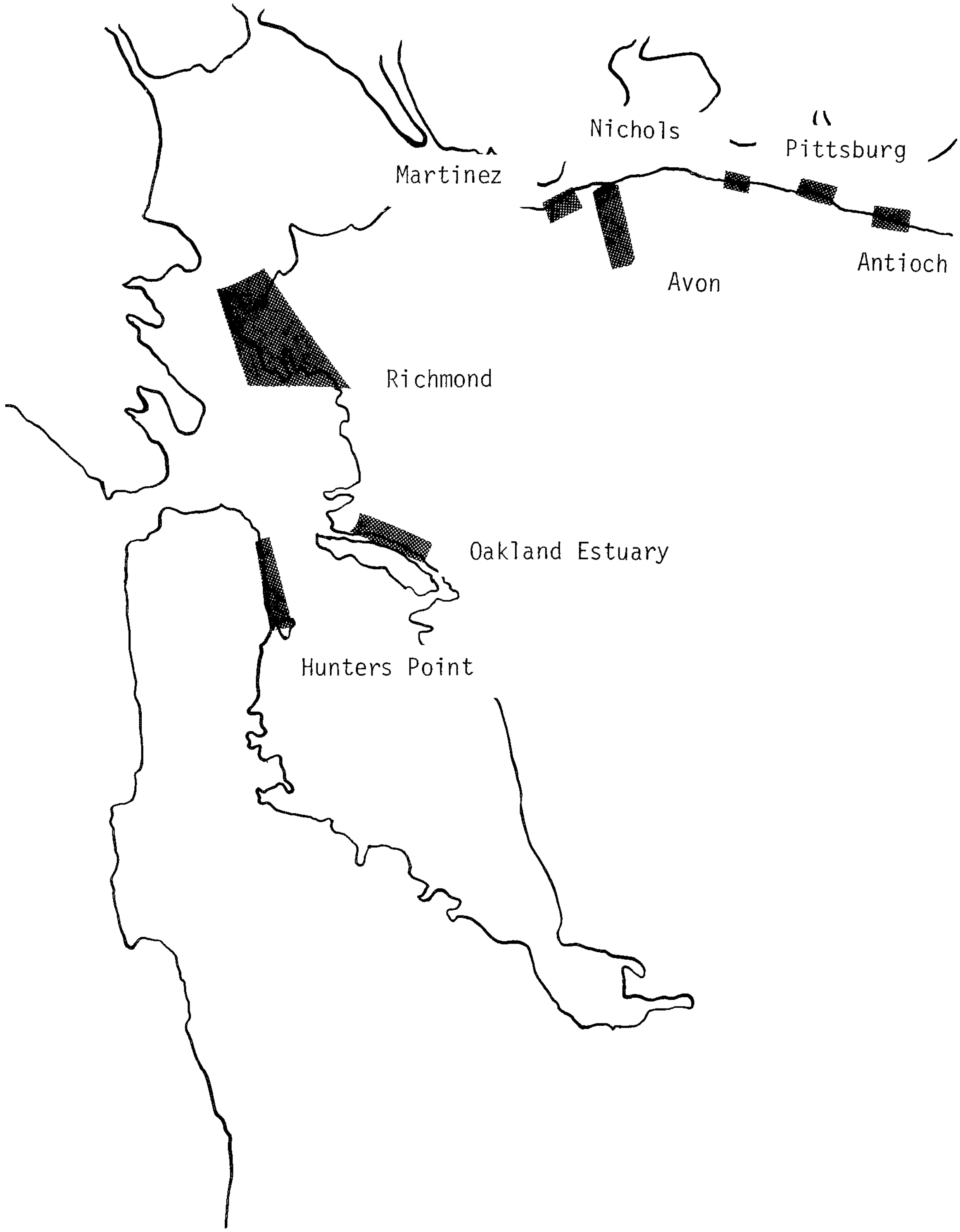


FIGURE 1. SAN FRANCISCO TEST SITE

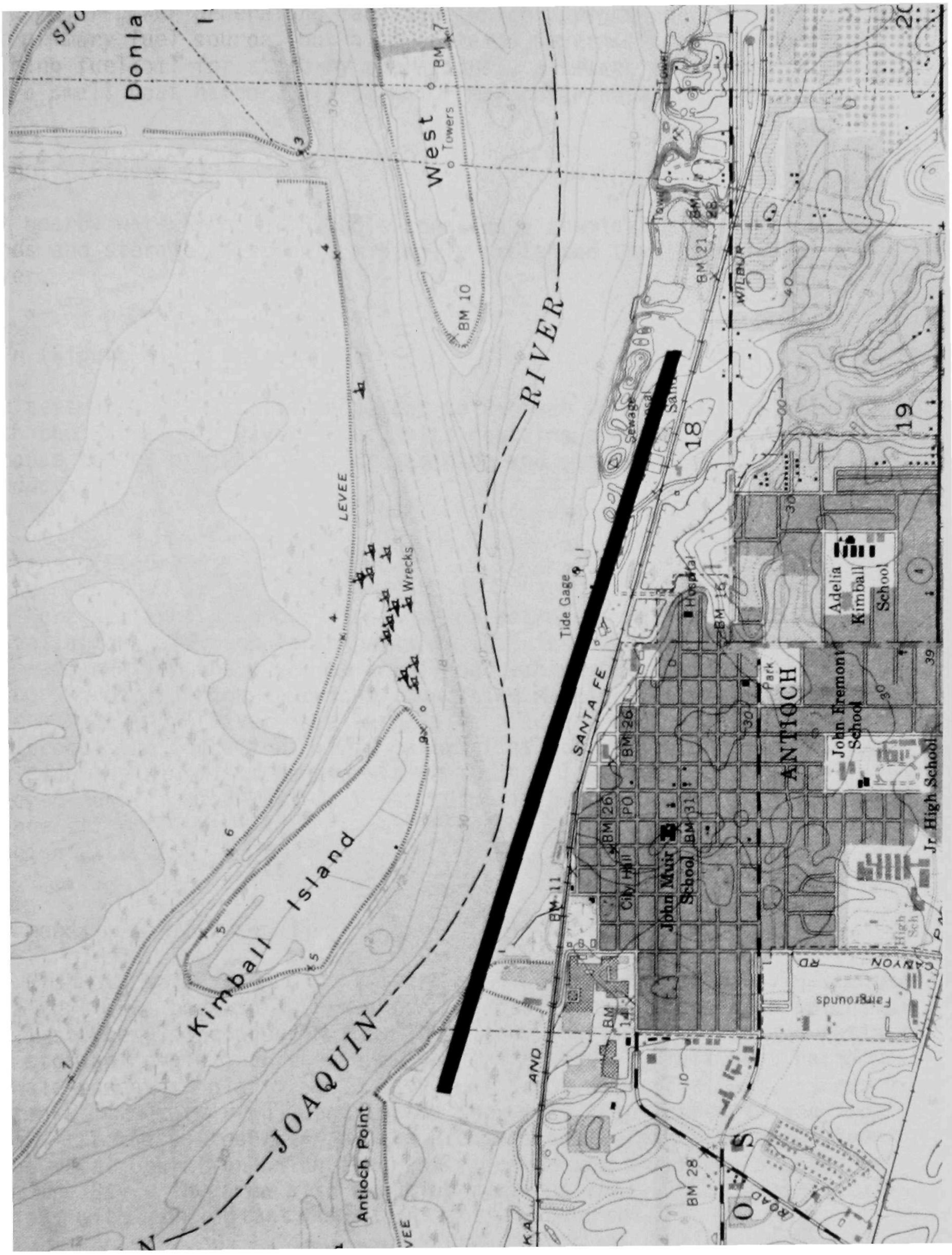


FIGURE 2. ANTIOCH TEST AREA

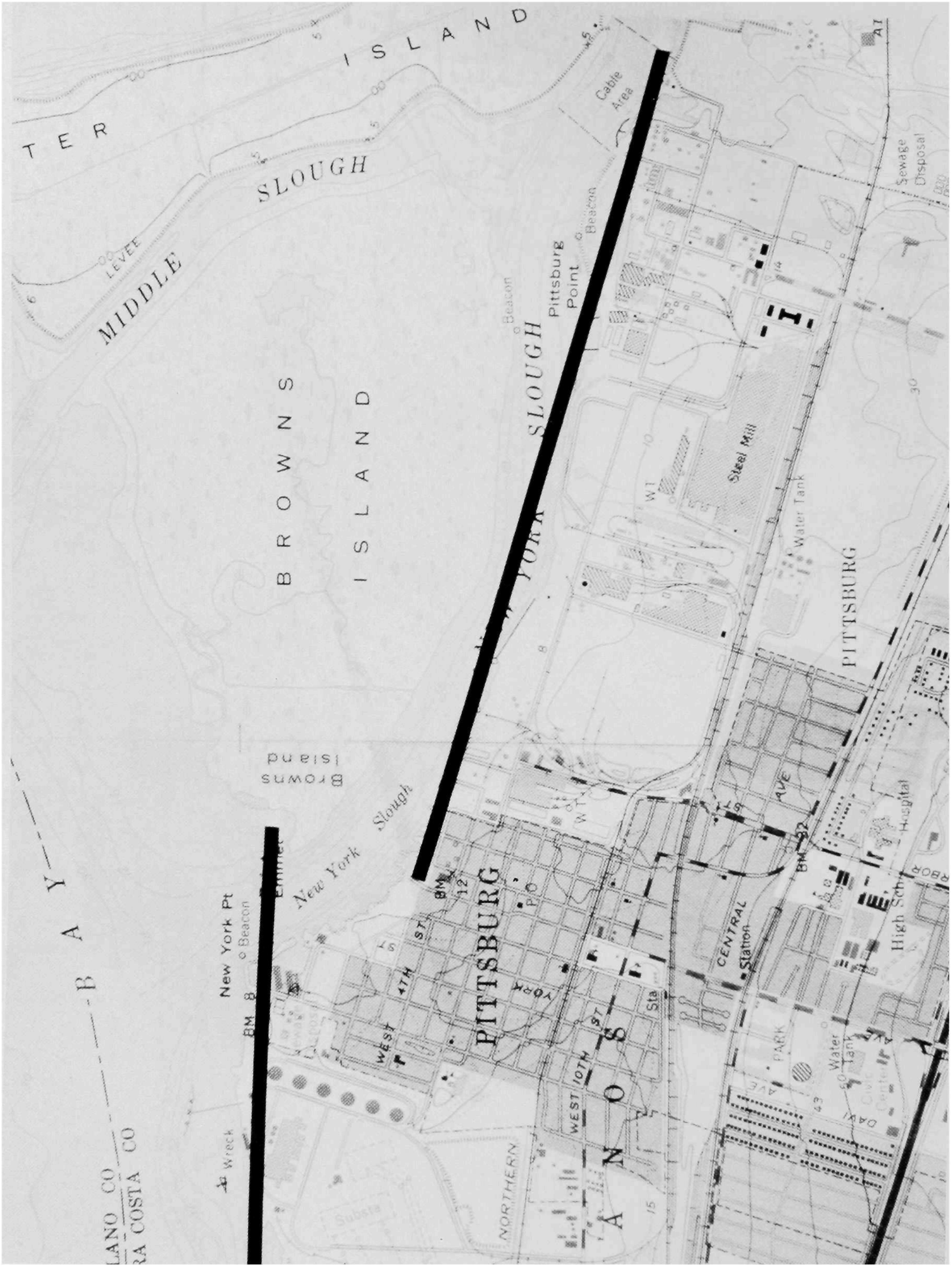


FIGURE 3. PITTSBURG TEST AREA

is a major power generating facility (which depends upon natural gas as its primary fuel source, but also contains several large storage tanks holding fuel oil for stand-by operations), a sewage treatment plant, and a small boat harbor, all of which may contribute spill problems.

Nichols (Figure 4)

The nearby waterfront at Nichols contains a chemical plant with holding ponds and storage piles only minimally protected (by levees) from the river.

Avon (Figure 5)

The test area at Avon lies adjacent to Pacheco Creek at its confluence with the Sacramento River. This site contains one installation of significance to the project, a major refining and storage area for petroleum products.

Martinez (Figure 6)

The Martinez area also contains a major petroleum refining and storage installation, although large parts of that installation are protected and removed from the river by a railroad embankment. At the south anchorage of the highway bridge connecting Martinez with the north shore of the Sacramento River is a large pile of discarded material from an ore processing operation. This material is not restrained from sloughing into the river and provides a continuous low-level source of discolored runoff. This out-wash has been visible regularly as a yellow-orange stain in the river; it could also be inundated during periods of high water.

Richmond (Figures 7 and 8)

The Richmond waterfront and refinery area on San Francisco Bay was chosen as a test area because it presents numerous installations with potential spill sources. Included in this area is another major petroleum refining and storage complex; furthermore, there are several small boat harbors, a whale-rendering plant, and a Navy fuel depot where fuel oil, stored in tanks immediately adjacent to the shore, is transferred to and from ships. At the southern end of the Richmond test area is an extensive scrap metal operation which frequently introduces hazardous substances into the Bay. The area also contains numerous small industrial installations with concomitant potential as spill sources.

Oakland Estuary (Figure 9)

On the Oakland Estuary, there are several installations which present

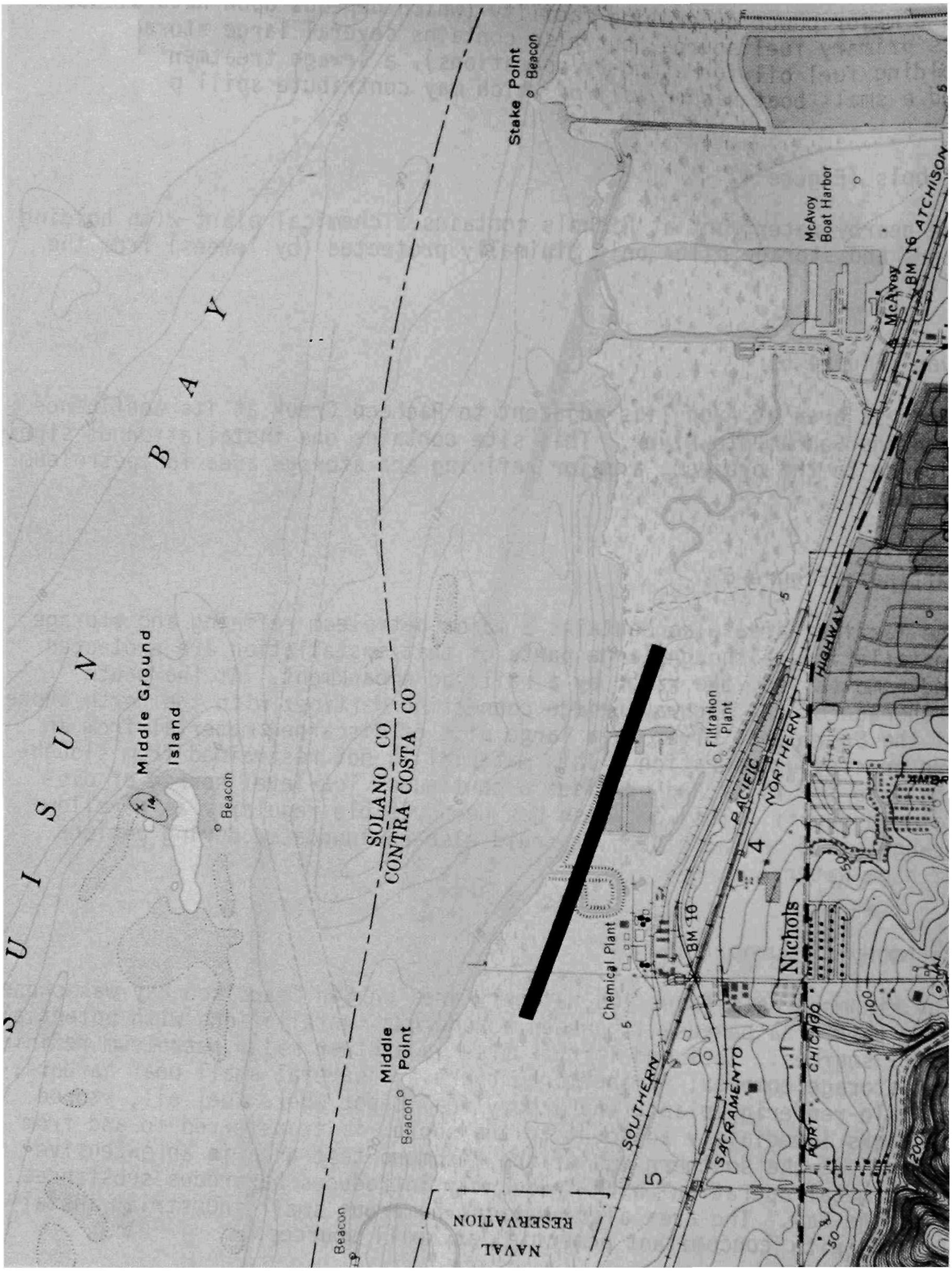


FIGURE 4. NICHOLS TEST AREA

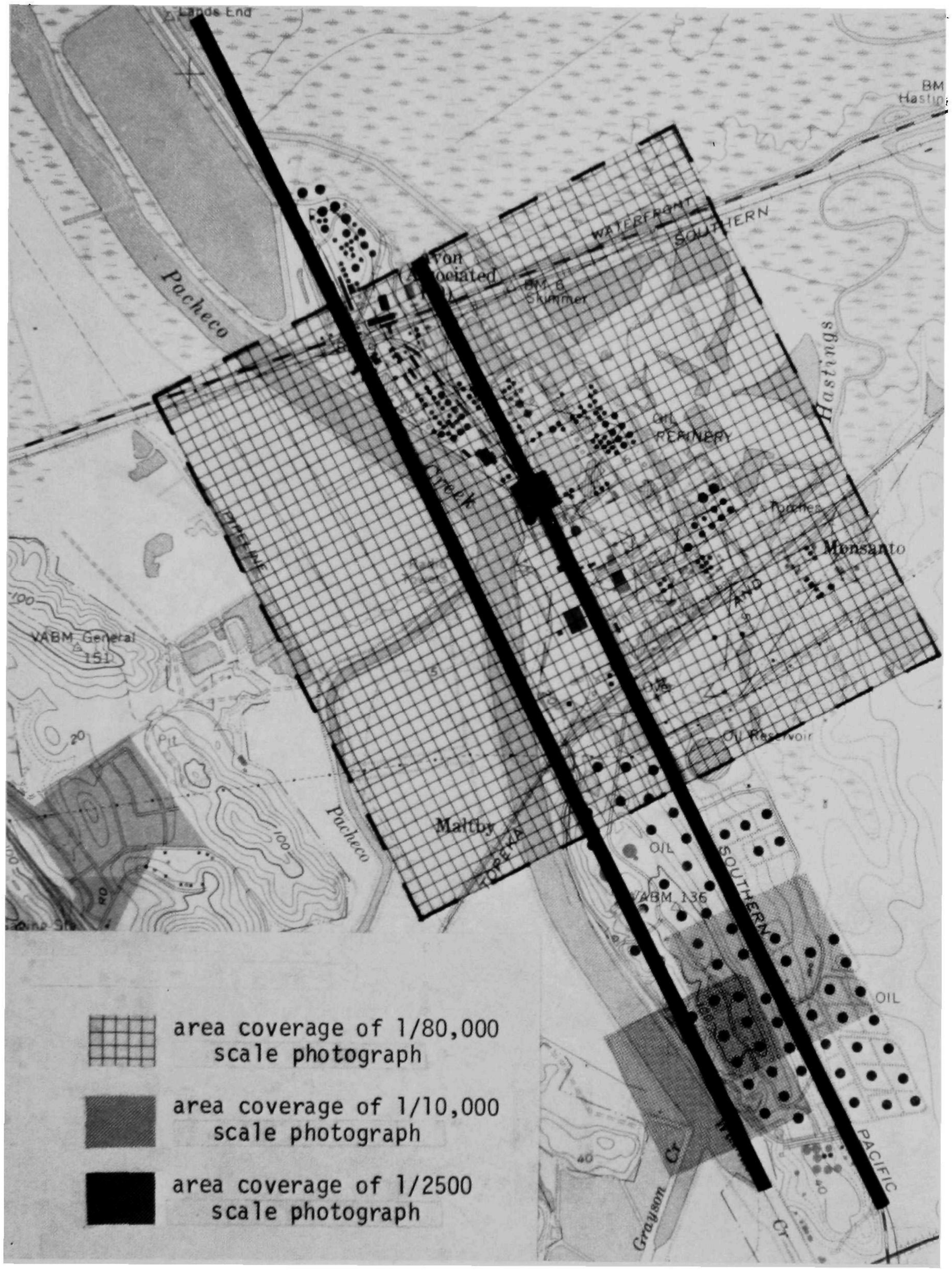


FIGURE 5. AVON TEST AREA

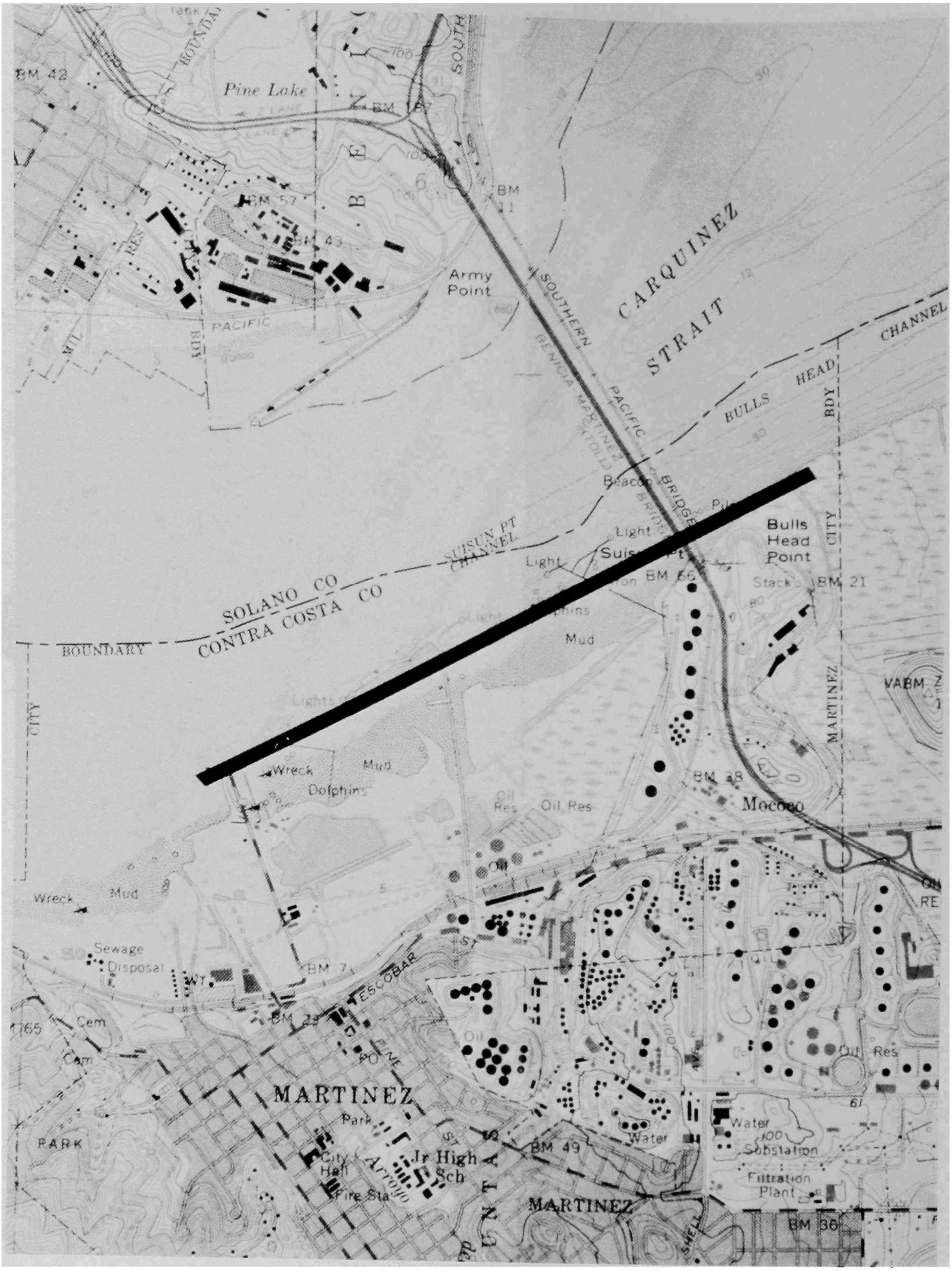


FIGURE 6. MARTINEZ TEST AREA

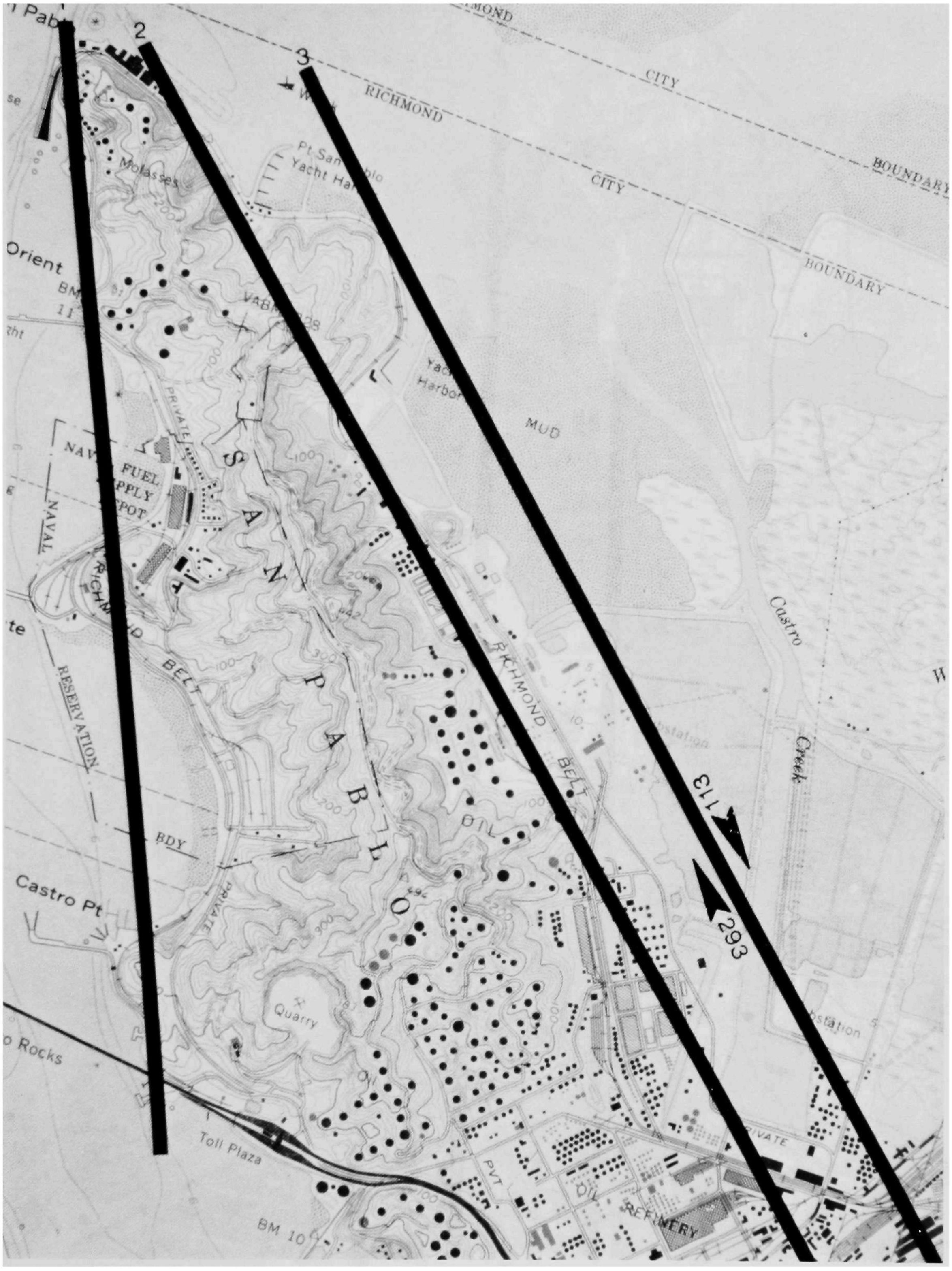


FIGURE 7. RICHMOND TEST AREA

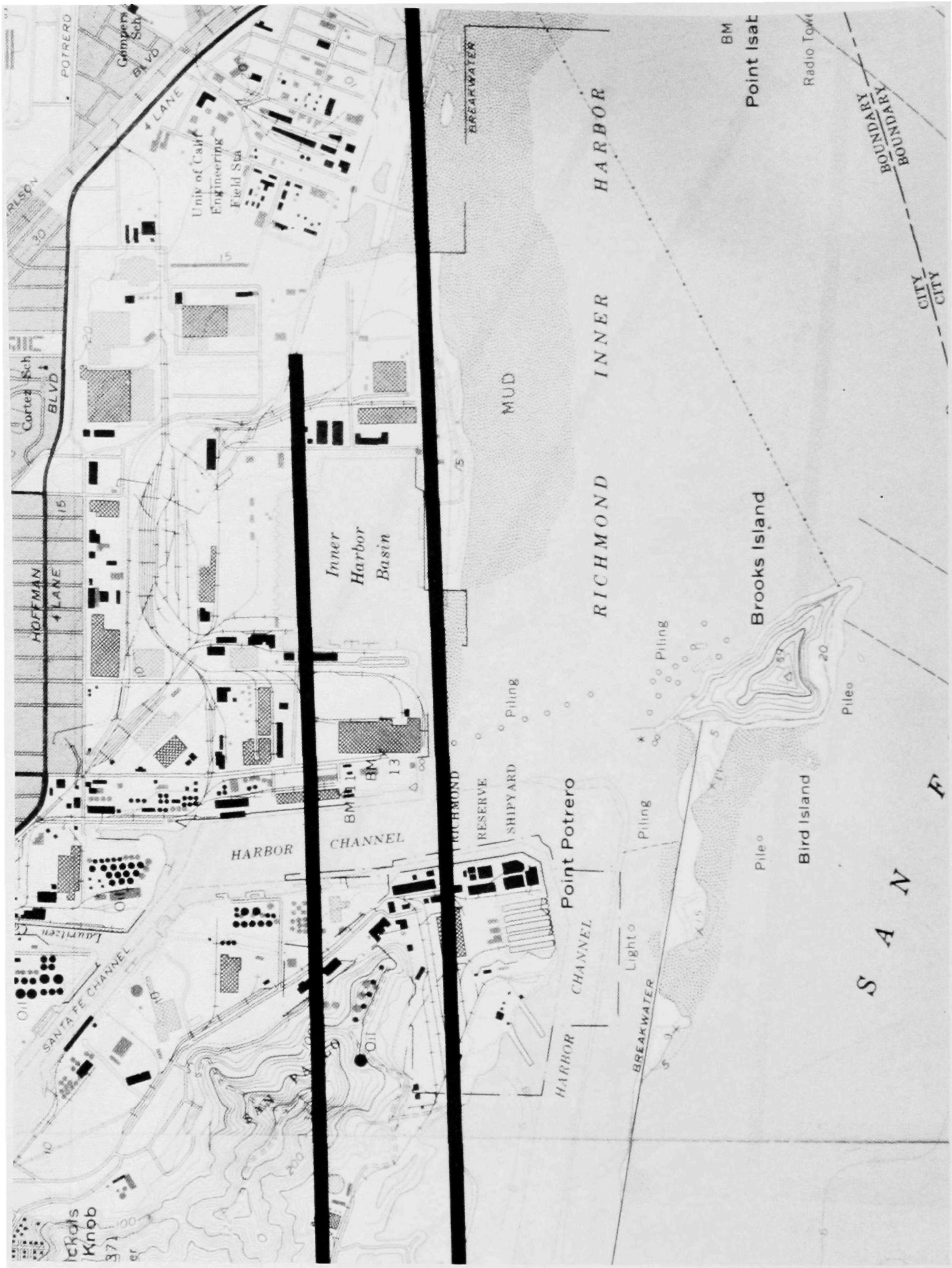


FIGURE 8. RICHMOND TEST AREA

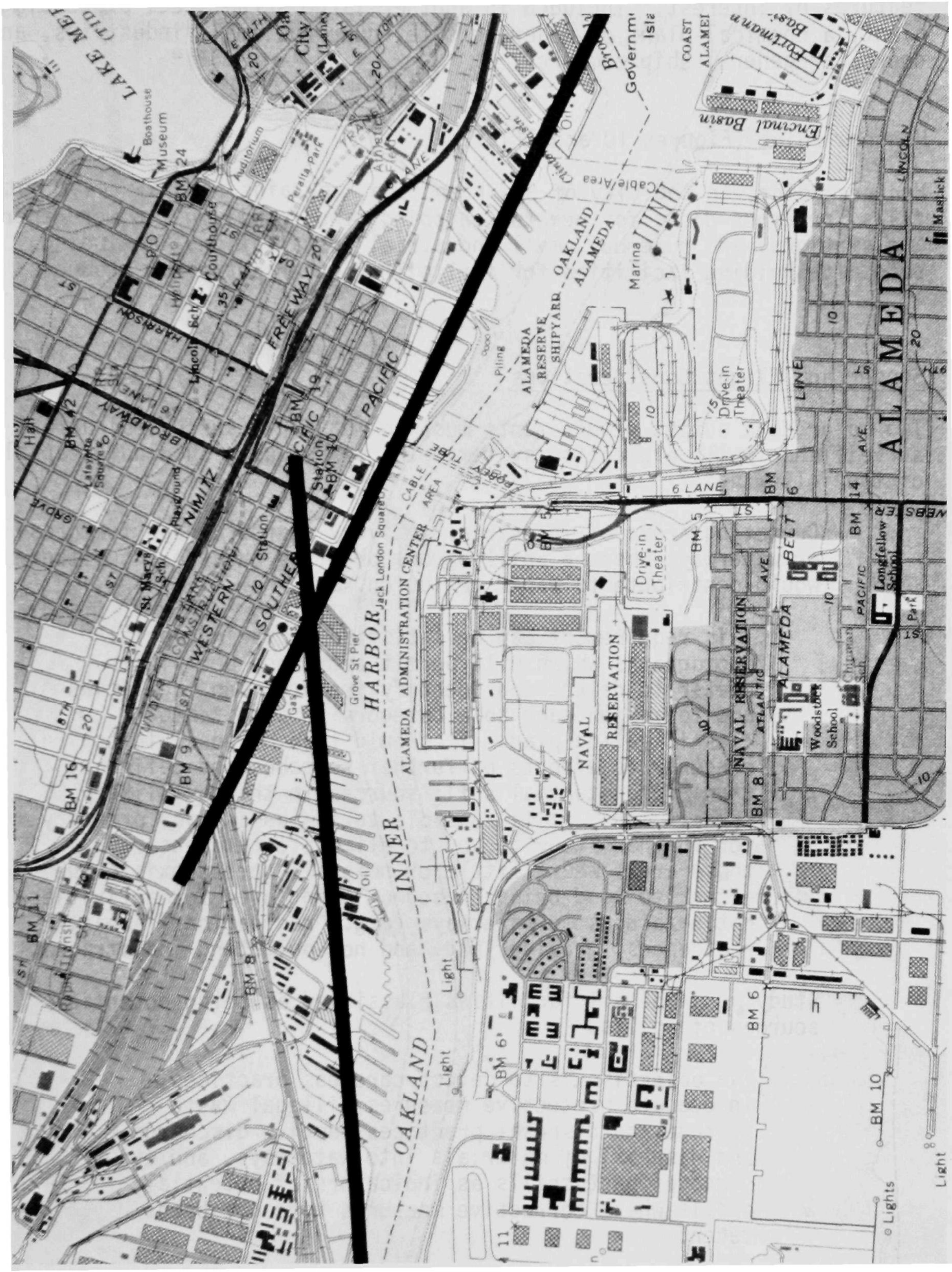


FIGURE 9. OAKLAND ESTUARY TEST AREA

features of interest. Included is another large scrap steel processing plant, a chemical plant of moderate size, numerous small industries, and docks for general ship commerce.

Hunters Point (Figures 10 and 11)

Hunters Point, in the City of San Francisco, contains several sewer outfalls, numerous docks for general shipping, two fossil/fuel power generating stations, and numerous small industrial installations, including some with holding facilities for fuel oil or other petroleum products.

Sensor and Flight Considerations

Two major data output requirements must be met for a successful aerial surveillance spill prevention system. The system used should be capable of the following:

- Detecting areas of industrial activity near drainage features or waterways where a spill of oil or other hazardous substance would contribute to water pollution.

  This requirement can be satisfied by taking aerial photographs which will permit a trained photointerpreter to detect and identify features and facilities and to assign each to a category in a suitable classification plan. It should then be possible to concentrate efforts on further searches and delineations for potential spill sources in the most likely areas. Thus, it is possible to assign a lower priority for further study to, or to eliminate completely, those areas where little or no spill threat exists due either to land being unused or being used for activities not hazardous to waterways (e.g., recreational areas, residences, grazing land, and non-polluting industries).

- Studying in detail facilities classified as being potential sources of spills.

  The objective is to detect careless practices, inadequate protective measures, illegal waste storage and disposal practices, active discharge and disposal of materials into waterways, and evidence of past spills as indicators of potential spills where corrective measures have not been taken.

A detailed study of facilities should be conducted only in those areas identified as potential contributors to spill problems. Data from the detailed study should be adequate to define both the types of material

FIGURE 10. HUNTERS POINT TEST AREA

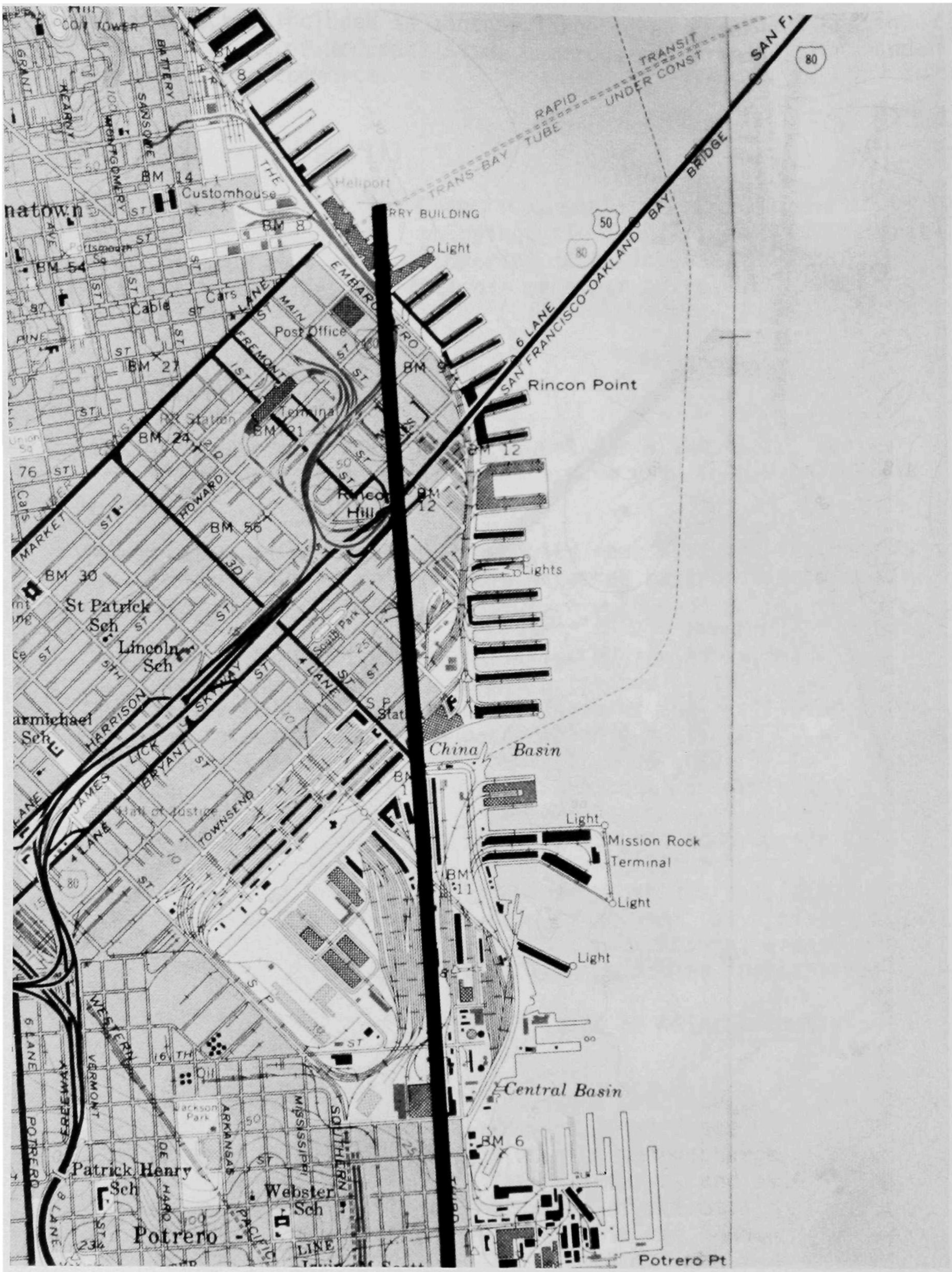


FIGURE 11. HUNTERS POINT TEST AREA

which may be involved in a spill and the corrective measures which should be undertaken. In most cases a minimum of ground visits for verification should be necessary.

In light of the two requirements listed previously, it is apparent that a single photographic mission would not be the most efficient way to obtain all necessary data, because of the requirement for a regional analysis under the first item and a highly selective localized approach under the second. Rather, data from the first mission can be used to select specific areas for coverage by a second mission.

Regional coverage should provide only enough detail to identify industrial complexes. Small area coverage should provide considerably more detail for obtaining information on specific spill threats.

There are a wide variety of sensors, cameras, films, and filters available to meet the requirements of regional and local surveillance, as well as vehicles to transport such a system to a target area. It is imperative that care be used in specifying the vehicle, camera system, and flight parameters, in order to optimize image acquisition operations.

Among the factors necessary to optimize image acquisition specifications, it is desirable to:

- Produce photographs at the smallest scale acceptable for the required interpretation accuracies

  Specification of an excessively large scale increases the cost of the photography (for example, costs per square mile are approximately 2.5 times more for 1/5,000 scale than for 1/10,000 scale - see page 107), requires the interpretation of more photographs than necessary, and obscures some regional trends which may be obvious on smaller scale photographs covering larger areas.

- Specify a film/filter combination which provides optimim contrast between the target features and surrounding objects

  Use of the proper film/filter combination may reveal information which is undetectable because of spectral characteristics of the target.

- Expose photographs during periods when solar energy best illuminates the features of interest

Small relief features are rendered more visible by using short focal length lenses which increase the stereoscopic parallax recorded at a given photographic scale. Long focal length lenses tend to decrease vertical exaggeration or "flatten" ground features at the same scale.

Atmospheric haze can seriously degrade aerial photography, particularly in the shorter wavelengths (ca. 380-500 nanometers). Conventional color film is not generally used from altitudes above 20,000 feet, because haze often renders the ground scene a low-contrast blue or green. However, color infrared film, which is used with a minus-blue filter (thus reducing haze effects), does not suffer to the same degree when used from altitudes above 20,000 feet. On clear days, conventional color film may be used from higher altitudes and will produce good color fidelity, but it should be noted that very clear days are atypical in industrialized areas. Therefore, color infrared film (Kodak film type 8443 or 2443) exposed through a Wratten 12 filter is commonly specified for photography taken at altitudes above 20,000 feet. Under light to medium haze conditions, the maximum altitude for conventional color films should be decreased to 15,000 feet. In conditions of extreme haze, even color infrared film cannot be used with success, because of the degrading effects of the haze.

Choice of appropriate large scale coverage is dependent upon more variables than is the case with choice of small scale imagery. Therefore, no a priori decision was made; rather, a test of various scales was devised in order to assess the merits of available choices of large scales. The scale test covered the range commonly available with conventional aircraft and camera systems, and, for continuity and comparison, extended from small scale (1/80,000) through various increments to very large scale (1/2,500).

At 1/2,500, square to circular features as small as 6 to 12 inches across can be seen on photography taken under fair to good atmospheric conditions. At 1/80,000, features such as individual automobiles can barely be resolved under good atmospheric conditions. Photography at a scale of 1/400,000, taken by NASA from U-2 aircraft over San Francisco Bay, was also evaluated to determine whether such photography might be useful for regional classification. Many of the requirements set forth for small scale coverage were not satisfied by such photography.

Four identical Hasselblad 500EL cameras, modified for use with 100-foot film magazines and equipped with interchangeable lenses of 80mm and 250mm, were used in the test. Shutters were electronically synchronized to provide identical coverage on each film/filter combination (Table 2), using exposure parameters as specified by the manufacturer. Due to the relatively small area to be surveyed, and the desirability of simultaneous exposures when evaluating several film/filter combinations, this 70mm format system was chosen as most compatible with the requirements of the feasibility demonstration. A similar multispectral array of larger format cameras would have been impractical.

Specifications similar to those for the photographic missions were prepared for acquisition of thermal infrared imagery, based on practices known to be useful for imaging pertinent industrial components. The daytime temperatures and associated thermal emission rates of most surface areas are quite different from those existing at night. Usually subtle industrial thermal sources are best recorded during the pre-dawn

Table 2. Film/Filter Combinations Used

Film	Filter	Remarks
Aerial Color (Kodak SO-397)	1A (Haze)	Records the ground scene in a nearly true rendition of the features as seen by the human eye. Provides maximum contrast among features whose major reflectance is in the visible spectrum. Provides very sharp images and good exposure latitude for various lighting conditions.
Color Infrared (Kodak 8443 or 2443)	Wratten 12 (Minus-Blue)	Provides optimum haze penetration while recording the ground scene in a variety of false colors which provide contrast among features of interest for vegetation and environmental studies. Provides sharp images and fair exposure latitude for various lighting conditions.
Panchromatic (Kodak 2402)	Wratten 47B (Plus-Blue)	Provides fair contrast between oil slicks and background water. Provides fair sharpness and exposure latitude for various light conditions.
Black-and-White Infrared (Kodak 2424)	Wratten 89B (Minus-Visible, Infrared Transmitting)	Provides good shoreline delineation between water and land. Provides good detectability of vegetation conditions.

hours. Since many industrial substances which might become spill threats are at temperatures other than ambient, thermal scanning provides much useful information even if one is not primarily concerned with thermal pollution.

In order to test the validity of these considerations, thermal infrared imagery was acquired over all test areas at night at an altitude of 5,000 feet and over the Richmond test area at two other times (mid-afternoon and evening) and at three different altitudes (1,500, 5,000, and 10,000 feet). At 1,500 feet, thermal anomalies of as low as one to two degrees centigrade and features as small as one to three feet in diameter can usually be detected; at 10,000 feet, however, thermal anomalies have to be at least three to five degrees centigrade and features have to be at least five to ten feet in diameter to be detected. Features exhibiting extreme temperatures, such as vent stacks, pipelines, and hot engines, can frequently be detected even if they are smaller than these minimum averages.

The infrared scanner employed was a Texas Instruments Corporation RS-14 (operating in the 8-14 micrometer spectral region), chosen for its excellent thermal and spatial resolution as well as its dependability and performance.

Photographic and Thermal Data Acquisition

Data acquisition began with a reconnaissance flight over the entire San Francisco Bay - Sacramento - San Joaquin waterfront to delineate candidate test areas for further surveillance. The next activity involved over-flight of the selected areas in order to obtain photography at a scale of 1/40,000 for determination of the exact sub-areas to be used during the remainder of the study. From the resultant series of photographs, five major test areas were selected for intensive study. One area was selected for the sun angle and photographic scale test and was overflown several times with the entire four-camera multispectral array, in order to obtain imagery at representative sun angles and at representative scales, as previously described. From the results of these overflights, times and altitudes for succeeding missions were selected to give optimum coverage of the remaining test areas.

All scale tests were scheduled to be flown at the same time under stable atmospheric conditions to minimize the effects of uncontrolled atmospheric variables and to eliminate changes caused by target area fluctuations. It was recognized that the findings from photographs taken under any set of atmospheric conditions may be different from those from photographs taken under other conditions. Nonetheless, major conclusions as to scale choice will be independent of all but the most degraded atmospheric conditions.

Sun angle tests were conducted to identify illumination angles which might tend to enhance or degrade the detectability of features of interest. The photographic flights for sun angle testing were scheduled on the same day as flights for scale testing to provide direct comparison between the two tests and to minimize target area changes which might be encountered by photographing the area on two different days. Flights were made during periods when the sun angle was approximately 10, 40, and 60 degrees above the horizon.

From the results of these tests, times and altitudes for succeeding missions were selected. On vertical photography, sun angle proved not to be a critical factor as long as the sun was at least 30 degrees above the horizon. It was decided that the large scale photography should be obtained at a scale of 1/10,000.

The various missions flown and the nature of the missions is shown in Table 3. Interpretation of the imagery from any given mission occurred before subsequent missions were flown, thus mission planning could be done on the basis of previously acquired data. Large scale photography was interpreted prior to interpretation of thermal imagery to provide a reasonable data base against which to judge the thermal data.

Ground Truth Rationale

In photointerpretation operations for spill prevention, the goal is to perform the necessary data collection functions exclusively by reference to the photographs provided, without undertaking ground visits. In many cases this goal can be achieved because the features of interest are easily recognized, counted, and measured on the photographs, and the photointerpreter is confident that his interpretations are accurate. In other cases, the interpreter cannot complete his data collection functions working with the photographs alone, either because the imagery is unsuitable (spectral band, scale, or quality not optimum), the feature does not lend itself to remote identification (such as identification of most chemical components), or the interpreter lacks the necessary experience to derive the needed data even though the features may be clearly identifiable by an experienced interpreter.

In many data acquisition operations, it is known at the outset that a combination of photointerpretation activities and ground checking is needed. Costs for ground visits and commensurate time factors can become quite high if care in designing the data collection methods is not exercised. It is therefore desirable to minimize ground checking requirements in order to control costs associated with data collection activities. Ground checking requirements for spill surveillance can be minimized in a number of ways:

- Photographic acquisition procedures and systems can be specified to maximize the amount of data obtainable from photointerpretation.

Table 3. Remote Data Acquisition

Mission	Area	Date
Visual Reconnaissance and Oblique Photography	San Francisco Test Site	19 July
Small Scale Photography	All	27 July
Scale Test	Avon	20 August
Sun Angle Test	Avon	20 August
Large Scale Photography	All	8-9 September
Thermal IR Test	Richmond	9 August 2030-2200 PDT
		1400-1430 PDT
	All Others	15 August 2300-0100 PDT

Table 3. (cont.)

Scale	Film/Filter	Sun Angle
Oblique	Color/1A Panchromatic/12	50°-60°
1/40,000	Color IR/12	50°-60°
1/2,500; 1/5,000; 1/10,000; 1/20,000; 1/40,000; 1/80,000	Color/1A; Color IR/12; Panchromatic/47B; B&W IR/89B	40°-60°
1/10,000	Color/1A; Color IR/12; Panchromatic/47B; B&W IR/89B	10°, 40°, 60°
1/10,000	Color/1A; Color IR/12; Panchromatic/47B; B&W IR/89B	30°-55°
(Altitude: 1,500; 5,000; 10,000 feet)	----	----
(5,000 feet)	----	----
(5,000 feet)	----	----

- Photointerpretation personnel can be trained in specific tasks and disciplines that increase the amount of data obtainable from photographs alone.

- Reference documents such as photointerpretation keys can be prepared, providing valuable aids to photointerpreters in identifying and comparing features seen on aerial images.

- Previous photographic records and interpretations can be consulted to provide additional data.

Ground truth can take several forms and can be obtained by a variety of methods. For spill surveillance, most ground truth information would provide additional information on potential spills of hazardous materials Because of the extensive areas that are involved, ground data would usually be obtained after the aerial photography has been acquired and interpreted and only in those places selected by photointerpretation. Ground data should support information from photointerpretation, either to provide specific identifications, enumerations, or delineations, or to determine the significance of features as a potential spill threat. When evidence is needed to support enforcement actions, it is essential that interpretations made on aerial photographs be verified by an additional data source, such as low altitude telephotography or on-site ground observations, to provide complete confidence in data developed.

Additional sources of ground truth data include consultation with industrial personnel responsible for the facilities in question and reference to photographic interpretations performed for similar purposes.

Ground Truth Acquisition

In order to identify features which could not be positively identified on aerial photographs, at least one ground visit was made to each test area. At this time, verification of imagery interpretation was made, and documentary photographs, on 35mm and 70mm format, were taken of important target features.

Verification was accomplished in one of several ways:

- Where project personnel were familiar with the facilities in question, their ground observations provided ground documentation.

- Where project personnel were not sufficiently familiar with a feature, consultation was arranged with management personnel at the facility in question.

- Where both ground access and management consultation were denied, appropriate state or local government officials familiar with the facility were consulted.

In that all major facilities to be surveyed were represented by two or more examples, extrapolation could be made from facilities where cooperation was extended to those where cooperation was denied.

Thus, officials in several industrial operations were interviewed in order to compile information on prevailing conditions and activities and on the relationship of various components to potentially spillable materials. For example, at one refinery, management personnel provided information on storage tank capacities and the volumes and temperatures of tank contents for comparison with data obtained through image interpretation.

Image Interpretation and Data Correlation

Small scale multiband photographs were interpreted to delineate areas of interest for assessment of spill threats and to classify facilities and land use practices. Areas which would require large scale color photographic coverage to obtain detailed information on actual spill threats or active sources of discharge were delineated on small scale coverage, as were areas where low altitude oblique photographs were desired. Large scale photographs were interpreted to define the specific location of spill threats and active outfalls. Many of the areas studied in the initial phase were eliminated from more detailed study, because they were recognized as unlikely areas in which to find objects or conditions of interest. In most cases, unwanted features were merely enumerated but not considered further. Features which fell within the area or subject of interest were then further interpreted.

All interpretation was performed by stereoscopic viewing wherever possible. Stereoscopic viewing was found to be superior to monoscopy early in the project, as it facilitates the interpretation of topographic features, natural or man-made, which are important to a spill prevention study. Monoscopy is best suited for gross identification and the rapid scan of small scale imagery when delineating areas for detailed study.

Interpretation of all test site imagery and detailed interpretation of the petroleum refinery in the Avon area provided the basis for evaluating several aspects of the study. Interpretation provided data for evaluating:

- Suitability of vertical photography in classifying land use activities
- Role of low altitude oblique photography as a supplement to vertical photography and as a substitute for ground photography
- Relative suitability of the four film/filter combinations
- Effects of sun angle variations on image interpretability
- Accuracy and limitation of mensuration using simple equipment

- ° Effects of different lens focal lengths and associated parallax factors on interpretability

All interpretation was done in a manner which would permit it to be related to an evaluation of aerial imagery in facility analysis for past, present, and potential releases of hazardous materials.

Interpretations of color imagery were made on original positive transparencies and on paper prints of the black-and-white photography. Although the usual amount of degradation of image quality occurred in the process of making black-and-white opaque prints, such degradation was somewhat offset by the inherently easier interpretability of positive prints as compared to negative transparencies. Positive transparencies were interpreted with both a simple stereoscope and a zoom stereoscope (Bausch and Lomb Zoom 240); paper prints were interpreted with a simple stereoscope only. The unique perspective view afforded by low angle oblique photographs combines aspects of both vertical aerial photography and ground views. In this study, the oblique photographs proved to be valuable for detailed interpretation, especially interpretation of objects having height but relatively little areal extent, such as fences and barriers.

As scale denominator numerically diminishes, the extent of topographic relief is obscured. This effect is greatest on small (70mm format) imagery due to the small area coverage. Topographic relief is important in analysis of potential spill hazards from sites on hills or ridges, as slope may render ineffective a revetment which, if on level ground, would adequately retain the contents of its enclosed tank. In addition, one must consider the effects of relief on the drainage of surface water into catch basins and holding ponds, possibly resulting in overflow. Since 70mm format covers only 6% of the area of 9-inch format at comparable scale, 1/10,000 scale 9-inch format photography should provide ample realization of local relief in most instances, whereas 70mm format does not.

If desired, a topographic study could be performed on a site such as the ridge along Pacheco Creek in the Avon test area (Figures 5 and 12), which contains a major part of the tank farm area. The tanks are situated on the sides and top of the ridge on excavated benches and are provided with banked earth revetments and drains to catchment basins. A detailed analysis of the adequacy of earthworks during catastrophic spills and of the fate of residue in catchment basins during periods of heavy rainfall is possible only with extensive photogrammetric contouring of these installations and their environs, an operation probably not justified in most cases.

Interpretation for identification and analysis of potential hazardous spills combines industrial classification with interpretation for specific hazard and protection features. The unique analysis desired necessitates interpretive aids, both to assist the trained interpreter and to provide instructional material for novices. Such keys for spill prevention would be constructed around a classification scheme which leads from gross activity identification to specific identification of hazards, protective measures, and evidences of previous problems.

A classification plan prepared for a specific discipline would contain many categories of features that are not of interest, as well as a comprehensive listing of those that are of interest. It was therefore necessary to compile a classification scheme that would segregate areas near waterways where further detailed study would be needed (and that would permit a determination of priority for spill threat analysis) from those recognizable as being of no consequence as potential spill sources. A further requirement was that the categories in the plan represent classes of features which could be recognized consistently in a logical sequence by image interpreters on imagery specified for spill prevention.

Spills of oil and other hazardous substances are most likely to originate from facilities wherein such products are stored, transported, or used. The initial two divisions in the classification scheme, detailed in Table 4, were related to the stability of such facilities:

- Static
  An installation which is a permanent feature

- Transient
  An installation or facility which is not permanent, even over a short period, such as ships, trains, and trucks used for transporting hazardous materials

The next major division in the classification scheme involved the types of materials which might contribute to the spill of oil or other hazardous substances and, obviously, involved classification as to solid, liquid, and gaseous materials. The classification under materials was not more detailed because of the difficulty of absolute classification or identification of a substance from aerial imagery; rather, that particular piece of information, while necessary, would almost always have to be provided by ground observation and perhaps by laboratory analysis of specimens collected during ground observation.

Another division involved types of activities which could lead to a spill. Such activities include mining, transportation, storage, refining and processing, land development, and others. Means were therefore developed for identifying such activities and their potential, in any given setting, for contributing to spill problems on or near water bodies.

All of the facilities and activities described, which are generally associated with the industrial activity and its material handling facilities, contained various protective measures designed to control spills. Therefore, the classification scheme included a category for protective features which would tend to retard or retain a spill, the integrity of which are therefore important to a spill prevention program. Such features include barricades, fences, revetments, dikes, moats, cooling ponds, and waste lagoons.

Table 4. Classification Scheme

Static Facilities

Tank farms
Raw material, by-product, or waste piles
Waste lagoons and cooling ponds
Terminals
Pumping stations
Refining and processing installations
Power plants
Pipelines
Slaughterhouses
Livestock pens
Junk yards
Garbage dumps

Transient Facilities

Railroad cars
Trucks
Grading equipment
Ships

Materials*

Solid
Liquid
Gaseous

Activities

Mining
Transport
Storage
Manufacturing
Refining and processing
Waste treatment and disposal
Land development
Forestry
Agriculture
Recycling

Protective Features

Dikes, levees, dams
Barricades and railings
Revetments
Moats and trenches
Automatic control devices
By-pass storage
Cooling ponds and waste lagoons
Derailing prevention devices
Channel markers
Floating barriers

Evidence of Previous Problems

Immediate Past

Vegetative alterations
Stains
Turbidity
Slicks
Fish kills
Thermal anomalies

Remote Past

Drainage patterns
Vegetative alterations
Stains
Residues and deposits
Thermal anomalies

* Photointerpretation will yield only these categories plus identification of material as raw input, output, or by-product. Ground truth will provide specific identities, such as chemical composition, radioactivity, etc.

Finally, indications of past spill problems would be good clues to areas where potential spill problems may exist. Therefore, categories were constructed for ground features which might indicate recent or past spill problems, including vegetative alterations, stains, thermal anomalies, drainage patterns, and turbidity.

When a classification scheme such as this is illustrated with ground and aerial views and structured to provide dichotomous choices in classification through each level, it becomes an image interpreter's key. According to the proposed scheme, a complete key would allow the interpreter to go beyond general identification of activity (e.g., refining and processing) to specific classification (e.g., oil refinery) of the facility or of sub-areas in the facility (e.g., tank farm) and still further, to include types of hazardous material probably present (e.g., highly volatile vs. less volatile petroleum products). Once the hazard had been so classified, the image interpretation keys would lead the interpreter into an analysis of associated hazards (leakage, rupture, etc.), protective measures (revetments, catch basins), and indications of past occurrences (stains, vegetative alteration) in order that he might assess the magnitude of potential or actual problems.

For purposes of the image interpretation tests in the present study, and as a demonstration of a method of classifying and analyzing spill sources, an abbreviated key to gross identification of facilities was constructed. The key is based on classification of a target site by determination of the type(s) of activity occurring.

In an operational situation, image interpretation keys would be extensive, due to the variety of activities and processes which offer potential hazards. In addition to extent of coverage, the keys would need to be periodically updated as industrial practices change.

While various objective measurements are commonly used to evaluate the characteristics of the image structure on film, there is very little correlation between such measurements and the amount of information that can be extracted by trained image interpreters. The human interpreter is a very powerful information processor in whom many complex visual and mental processes take place during the analysis of a photographic image; these processes can govern the amount of useful information which he derives from that image. It is difficult to relate a photographic quality measurement obtained at several points on a photograph to the information an interpreter can perceive by viewing that same photograph in its entirety. Therefore, the information obtained by a group of qualified interpreters from the various film records, rather than various quantitative measurements of image parameters, was used as the basis for rating the sets of photographs taken with different films and filters and at various scales.

From preliminary study of the aerial photographs tentative conclusions were drawn regarding the interpretability of each film-filter-scale combination. Image interpreters, all of whom were unfamiliar with the target areas, were asked to make judgements relating to the interpretability of particular target features on these various combinations. The responses to these questions were scored by comparing them with "ground truth" data. The resulting information was used to define film-filter-scale specifications for an aerial surveillance spill prevention system.

Correlating the responses of a group of photointerpreters requires a careful analysis of the types of information desired (identifications, measurements, enumerations, comparisons), the quality of photographs (sharpness, contrast, color or tonal fidelity, stereoscopic parallax), the atmospheric and illumination conditions (haze, clouds, sun angle), and the experience of the image interpreters. Because the interpreters' responses are subjective, there will usually be a spread in answers which complicates the scoring system.

A questionnaire and a response sheet were prepared, on which each interpreter submitted his judgements. Results of the image interpretation tests are presented in section V.

SECTION V

RESULTS

The imagery in this section has been compiled to illustrate significant findings and to demonstrate the usefulness of multispectral remote sensing techniques for spill prevention.

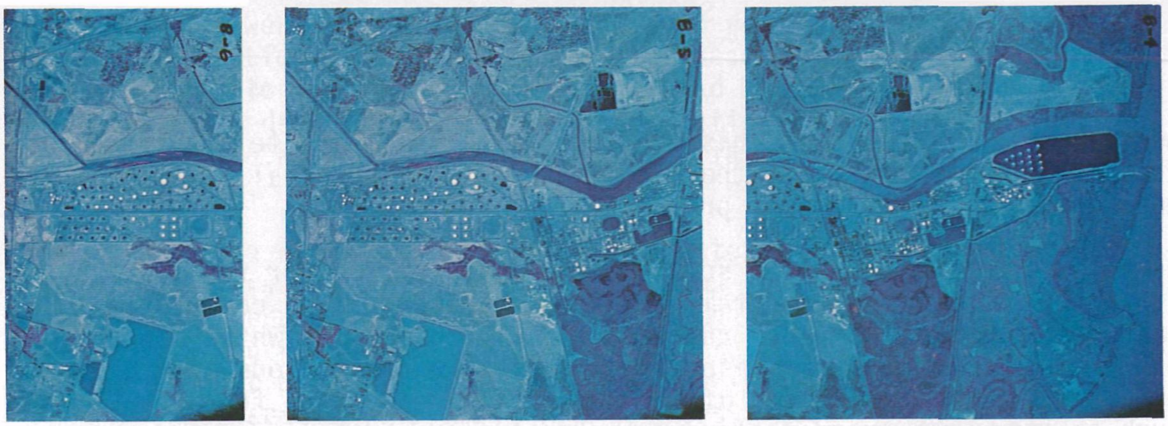
The color photographs in the scale test should be used for familiarization with the increase in detail and the decrease in area covered as scale denomination increases numerically. The black-and-white photographs are useful for comparison of film/filter combinations and for evaluation of the appearance of various easily recognized features (such as waterways, roads, storage tanks, trees, and buildings) on various images, including the oblique views.

Having made these comparisons, the usefulness of remote sensing for classifying ground features, detecting potential sources of spills, and locating actual discharges of oil and other hazardous materials will be more obvious. The difficulties in actual identification of certain activities and materials is evident when one examines the imagery.

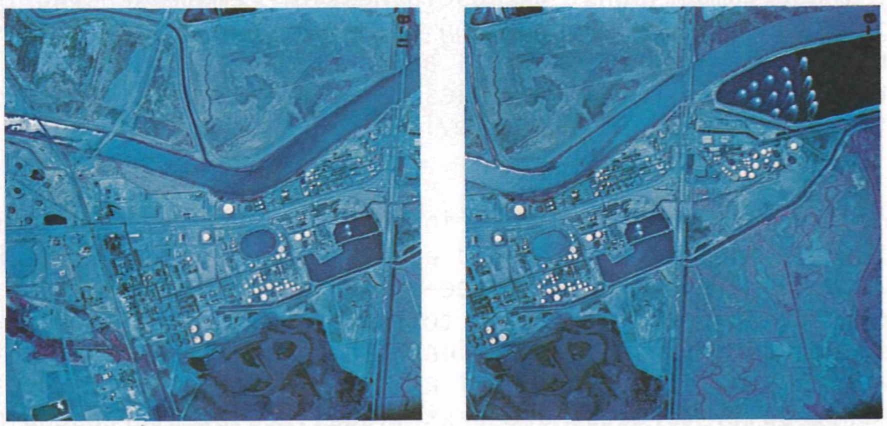
In order to visualize the above relationships, many of the photographs contained in this section are mounted as stereograms and should therefore be viewed with a stereoscope for three-dimensional interpretation. A large number of features of interest to this study can be seen on single photographs; however, their interaction with other man-made objects and with the natural environment, as well as with topographic features which influence spill threats, are best visualized by stereoscopic viewing.

It may be noted that some photographs in the 70mm stereograms are out of linear alignment due to drift and heading change of the aircraft as these photographs were exposed. In addition, the amount of overlap between the two members of a stereogram may vary somewhat. Despite the minor annoyance which such problems may cause, it was considered that the photographs should be presented in this report in the form in which they came from the photographic mission in order to realistically illustrate imagery from operational systems. The advantage to viewing such material in this direct manner stems from avoidance of the image degradation inherent in any corrective procedures.

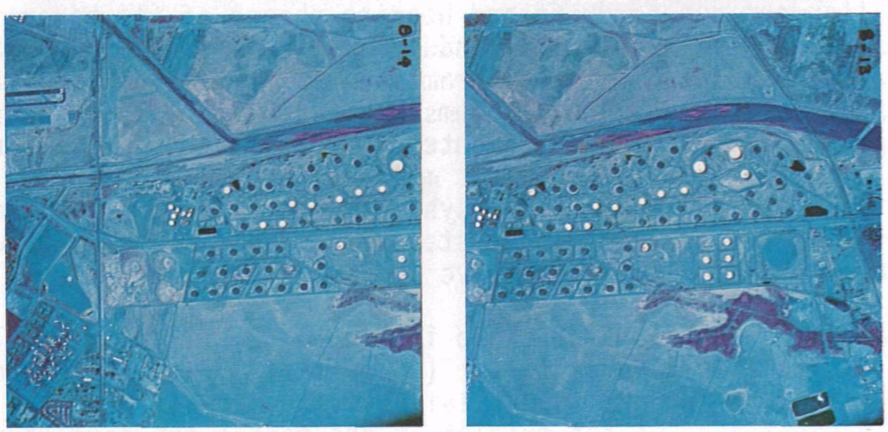
Small scale photographs such as those in Figure 12, taken with color infrared film and a Wratten 12 filter (color IR/12), are useful in the classification of areas into industrial activity categories. The photograph on the right side of the triplet at the top of the page (scale 1/80,000) shows an oil refinery located at the confluence of Pacheco Creek and the Sacramento River in the Avon test area. On the right is a large bio-oxidation pond, commonly associated with oil refineries. At the bottom center of the right hand photograph, a coke pile (residue from oil refining) can be seen. Surface drainage features should be



Tank Farm and Oil Refinery, 1/80,000



Oil Refinery, 1/40,000



Tank Farm, 1/40,000

FIGURE 12. AVON TEST AREA. Color IR/12, August 20, 1971

noted and compared with Figure 20. The left hand photograph of the triplet shows a tank farm (clustered storage tanks) where petroleum products are held for processing and shipment. The center photograph provides 60% graphic overlap for three-dimensional viewing of the imaged scene.

Many of the features necessary to spill threat analysis cannot be discerned on these 1/80,000 scale photographs. Such features include pipeline routes, revetments around tanks, and transportation terminals.

The lower two stereograms are of the same area, but at a larger scale (1/40,000). Comparison of the features observed on the upper photographs with those on the lower photographs demonstrates that it becomes possible at this scale to discern some large protective features such as dikes and levees; others, such as barricades and fences, do not image. Note that storage tanks with white tops can be resolved, while tanks with dark tops tend to blend together.

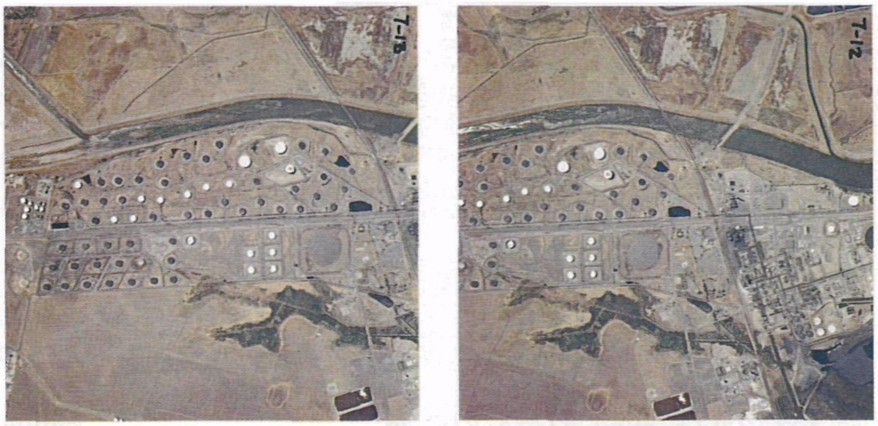
At this time of year (summer) in this area, most vegetation does not appear red on color infrared/12 photography. The predominate vegetation is annual grasses which have dried and are therefore not reflective of solar infrared energy. Wetland vegetation does appear red, however, because it is physiologically active and therefore has a high solar infrared reflectance. This figure should be compared with Figure 13.

The 1/80,000 scale color photographs taken with Kodak SO-397 film and using a Wratten 1A filter (color/1A)(at the top of Figure 13) are of unusually high quality due to the absence of significant amounts of atmospheric haze at the time of exposure. The features seen on Figure 12 (tank farm, refinery, coke pile, bio-oxidation pond, etc.) should be compared with the same features on these photographs. At the 1/40,000 scale, it is possible to follow some pipeline routes and, at the 1/20,000 scale (Figure 13), the pipeline routes are easily visible, as are some supporting structures for elevated pipelines.

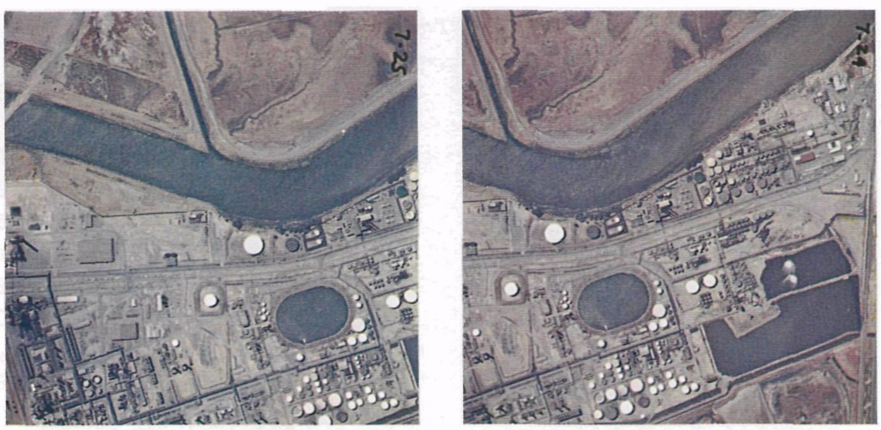
The stereogram at the top of Figure 13 should be compared with the black-and-white photographs in Figure 19. Although most features are visible on the black-and-white photographs, qualitative evaluations based on them are more difficult to make. For example, on the black-and-white photographs, one might mistakenly identify the tonal changes seen on the outer sides of the oval-shaped reservoir in the center of the 1/20,000 scale example as green vegetation, indicating seepage and, thus, a point of potential levee failure. On the corresponding color photographs, the features can correctly be identified as seasonal, brown vegetation and therefore not indicative of a point of active seepage. Green vegetation can be seen along the creek banks in the upper half of the photograph. Vegetation evaluation is more easily accomplished using color IR/12 photography, as seen in Figure 22. Algae floating at the border of the reservoir are also visible.

Seasonal changes relating to water level and vegetative conditions may be important to spill prevention surveillance. Such changes can affect

1/80,000



1/40,000



1/20,000

FIGURE 13. SCALE COMPARISON, AVON TEST AREA. Color/1A, August 20, 1971

the magnitude of the threat where heavy rainfall weakens structures, increases the volume of hazardous material which might spill into a waterway, or causes flooding, inundating inadequately protected waste storage areas. Seasonal differences in vegetation can also mask important features or clog important drainage pathways and holding areas.

The stereograms in Figure 14 were taken on color/1A at a scale of 1/10,000. The upper four photographs were taken with an 80mm (normal) lens and the lower three photographs with a 250mm (telephoto) lens. Topographic relief is more easily visualized on the photographs taken with the shorter focal length lens because of the larger lens angle and the lower altitude required to achieve the same photographic scale. When viewed stereoscopically, levees, tanks, and buildings appear to be taller in the upper series of photographs than in the lower series. This effect makes it possible to photogrammetrically estimate heights with greater accuracy on photographs taken with a shorter focal length lens and also to determine whether levees and revetments are incorporated at each tank site.

An oil spill stain can be seen on the ground at "A". An unrevetted tank is located on the creek bank at "B". Railroad tank cars can be seen at the loading point at "C" and a fossil-fuel-power generating plant is at "D".

The 1/5,000 scale color/1A photographs in Figure 15 provide more detail than the previous photographs, but they cover less area. At this scale, it is possible to determine the presence or absence of such features as elevated pipelines and supporting structures ("A"), protective fences along pipeline routes ("B"), oil leaks at pipe valves ("C"), pipelines running through levees ("D"), pumps ("E"), and dark stains on the ground from past oil spills. Levee structures can be seen around storage tanks in the lower photograph, as can individual pipelines. In some areas, incipient levee erosion is apparent ("F").

The photographs in Figure 16 are considered to be of unnecessarily large scale (1/2,500) for the requirements of a spill prevention system. No additional significant information for detecting spill sources was gained by use of this large scale photography over that which was obtained at smaller scales. Perhaps in areas where high concentrations of industrial activities are present, one would want to specify 1/2,500 scale photography, but then only in very limited areas because of the time required for interpretation. The oil spill at "A" on Figure 14 appears at "A" on this figure. It is also possible to see fences and gates on this photography ("B"). Interpretability of specific features seen at this scale can be compared with interpretability at other scales by returning to previous figures. As a photointerpreter gains experience in searching for potential spill sources, and as his efficiency increases, he will be able to use smaller scales for interpretation.

The reddish catch basin, seen in this series of stereograms (Figure 17) at scales of 1/10,000, 1/5,000 and 1/2,500, contains diesel fuel which

80mm (Normal Lens)

250mm (Telephoto Lens)

FIGURE 14. ILLUSTRATION OF VERTICAL EXAGGERATION, AVON TEST AREA.
Color/1A, 1/10,000, September 9, 1971

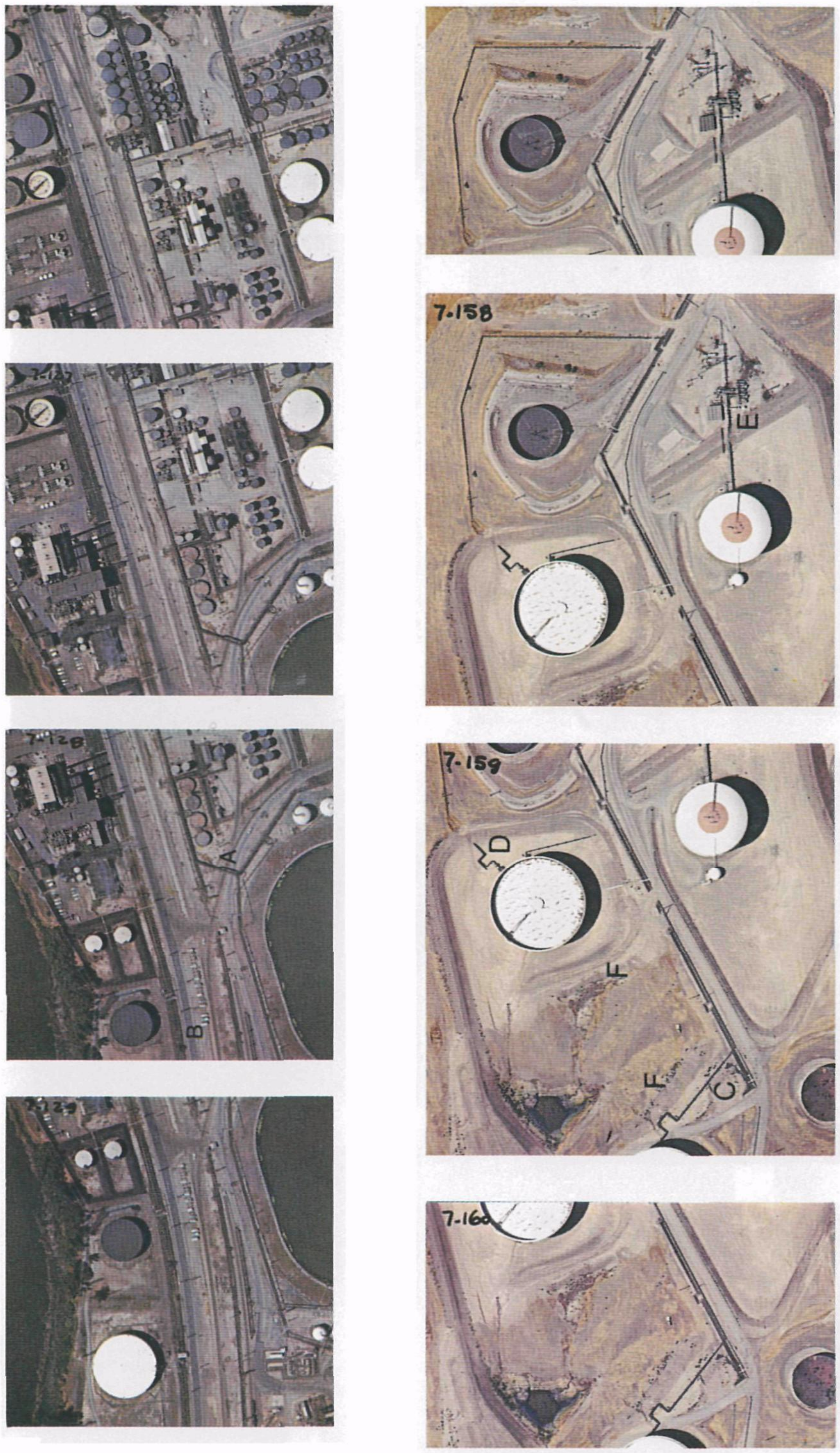


FIGURE 15. LARGE SCALE COVERAGE, AVON TEST AREA. Color/1A, 1/5,000, August 20, 1971

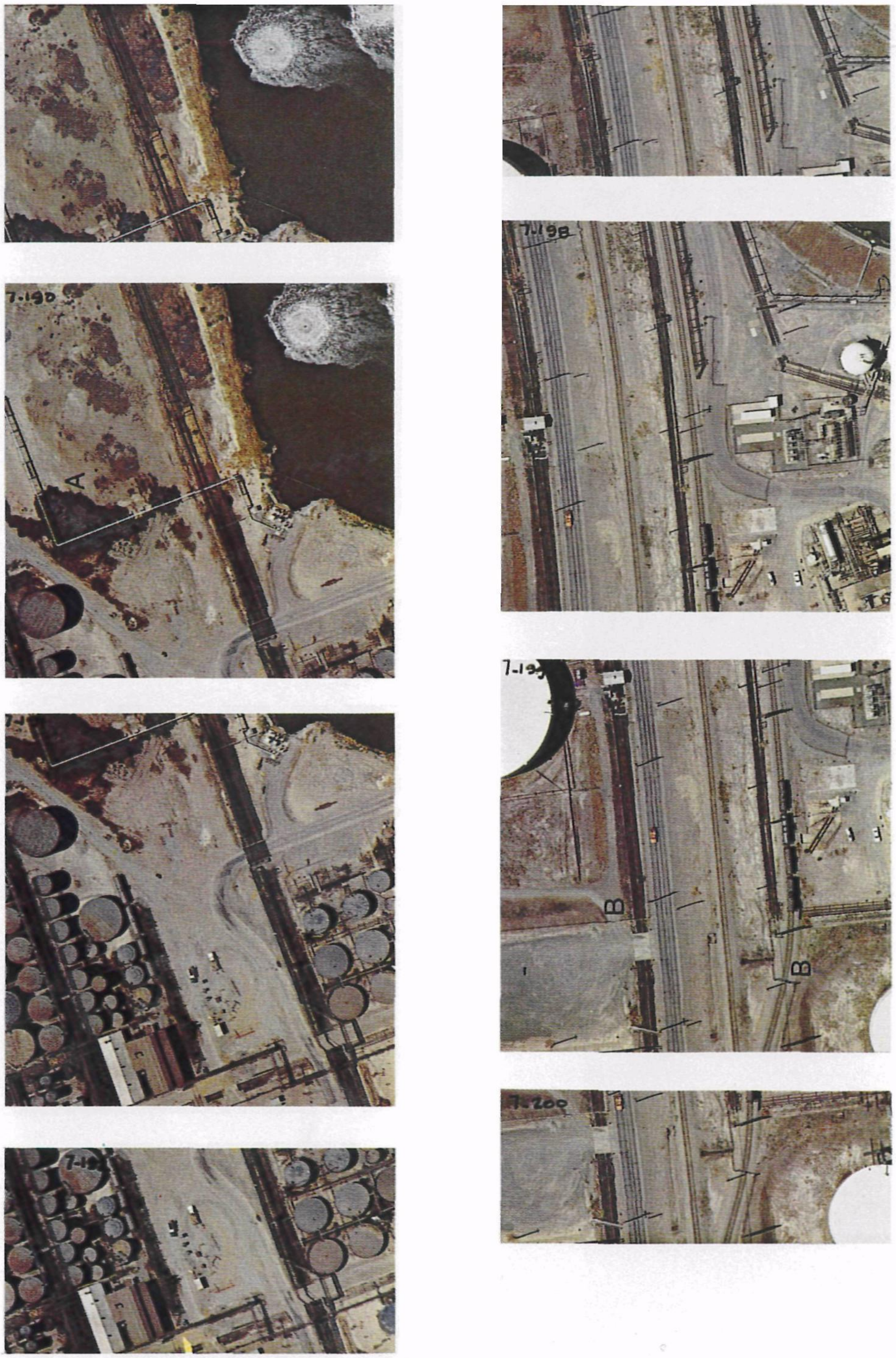
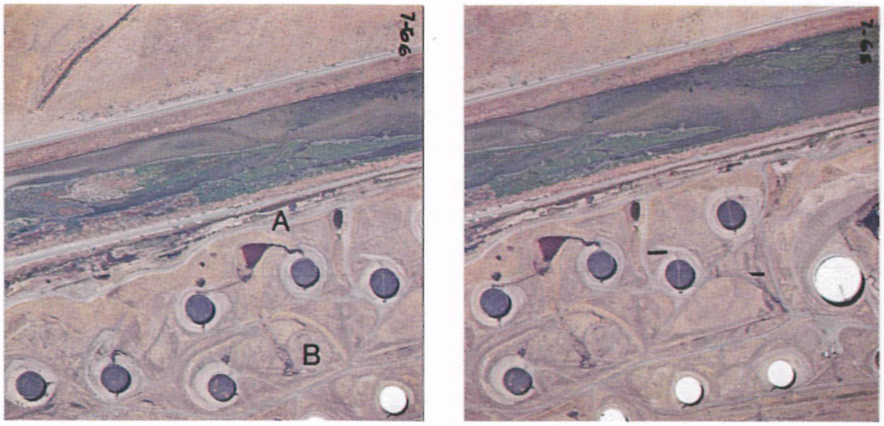
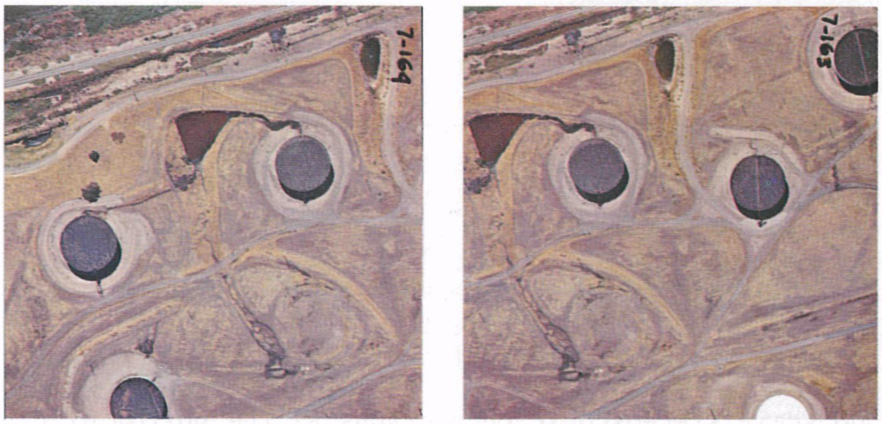


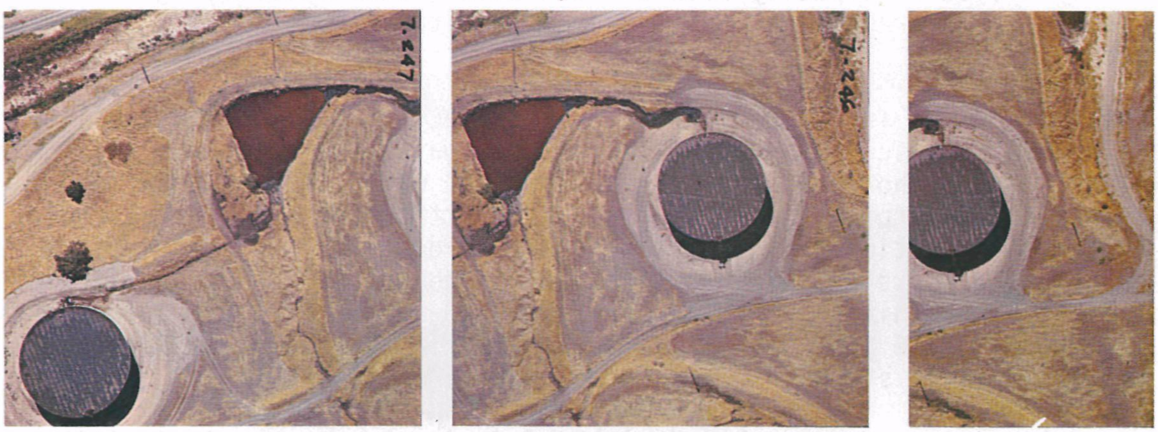
FIGURE 16. VERY LARGE SCALE COVERAGE, AVON TEST AREA. Color/1A, 1/2,500, August 20, 1971



1/10,000



1/5,000



1/2,500

FIGURE 17. OIL DISCHARGE, AVON TEST AREA. Color/1A, August 20, 1971

was inadvertantly drained from the tank at the right of the basin. The same reddish liquid is present at "A" in the ditch along the roadway, indicating further drainage of a quantity of the same type of material. The presence of this material was brought to the attention of refinery personnel, who subsequently reclaimed about 1,000 barrels of diesel fuel which was floating on the water in the catch basin. This oil spill was unknown to refinery personnel, who indicated that much of the product would have been lost to evaporation and seepage had it not been detected by photointerpretation.

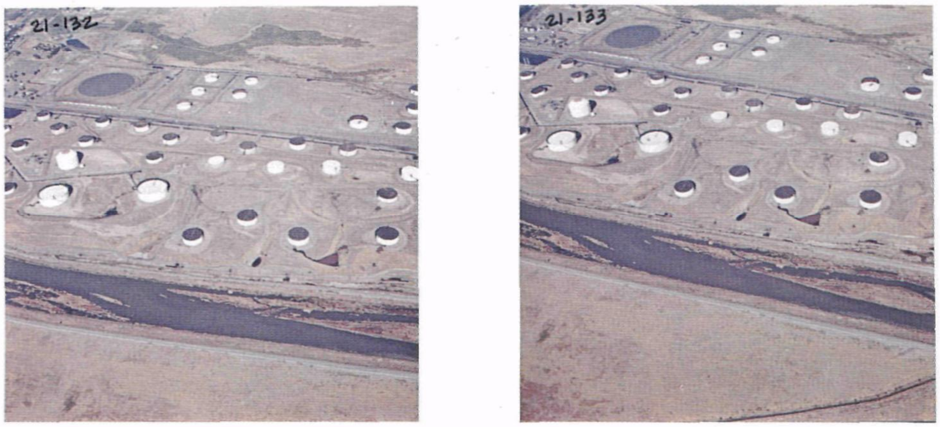
A tank has been removed at "B"; the potential spill threat from tanks on this hill is aggravated by the fact that the slope leading to the waterway is quite abrupt in some places. Although most detail is visible at the largest scale, area coverage is so reduced as to make topographic judgements nearly impossible. On a 9-inch format, 17 times more area would be covered at comparable scale, thus alleviating topographic obscurity.

These photographs should be compared with those in Figure 18, in which the upper row of photographs are aerial oblique views of the same scene. The stereo pair of oblique photographs at the top is helpful in evaluation of the spill threat from tanks on the hill, although some areas cannot be seen as clearly as in the vertical view because of the topography. If stereographic vertical coverage cannot be obtained, the photographic team can take stereo oblique photographs for evaluating .ndustrial activities by three-dimensional viewing. The black-and-white oblique photograph at left center does not reveal the reddish color of the catch basin. At right center is a ground view.

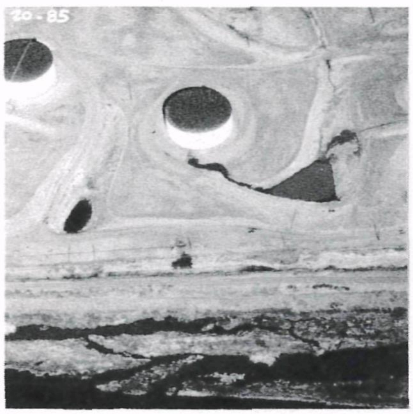
The 1/5,000 scale stereoscopic photographs at the bottom of Figure 18 show a catch basin with an overflow pipeline ("A") connecting the catch basin with a drainage ditch. Oil can be seen in the basin, which is nearly filled to capacity with oil and water, thus restricting its usefulness for receiving liquid from nearby tanks if a spill should occur.

The photographs in Figure 19 were used in testing the interpretability of the various scales and film/filter combinations employed in this study. These photographs should be compared with Figures 12-16 to assess the interpretability of black-and-white photographs versus color photographs; notice that it is difficult to delineate natural surface drainage networks on this black-and-white photography. A comparison of the black-and-white photographs in Figure 20 with the color photographs in Figures 12-16 indicates the interpretability of features such as vegetation, oil stains, fences, pipelines, and storage tanks.

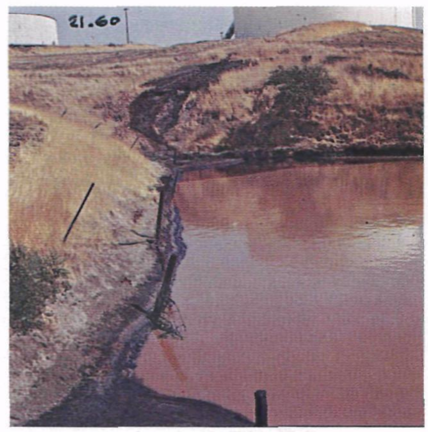
The delineation of water boundaries and drainage networks is facilitated by the use of black-and-white infrared photography taken with a Wratten 89B filter (B&W IR/89B), as shown in Figure 21. Because water absorbs almost all energy in the near-infrared region of the spectrum, water will image black on a positive infrared print. This dark tone contrasts



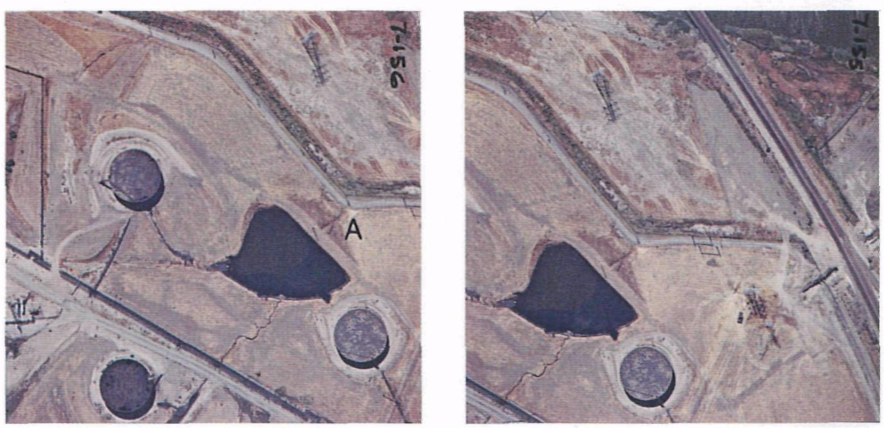
Color/1A, October 5, 1971



Black-and-White IR/89B, October 5, 1971

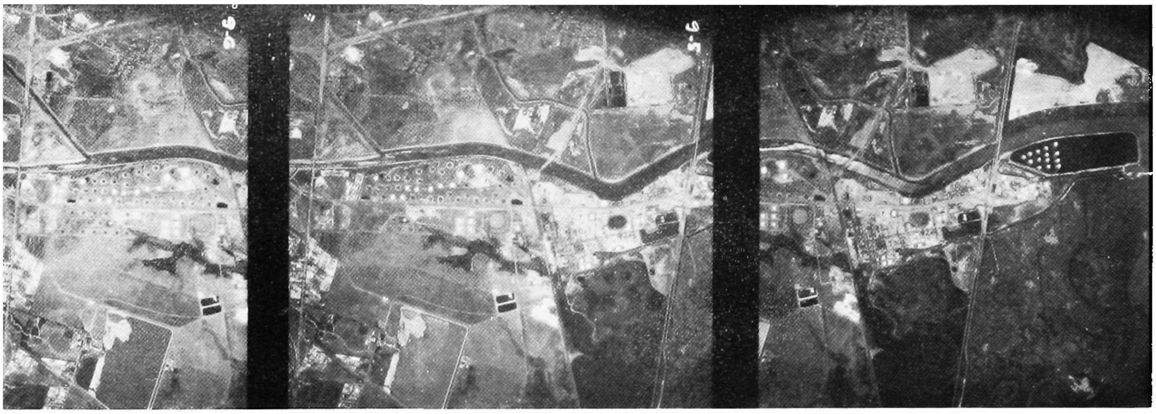


Color/1A, September 23, 1971

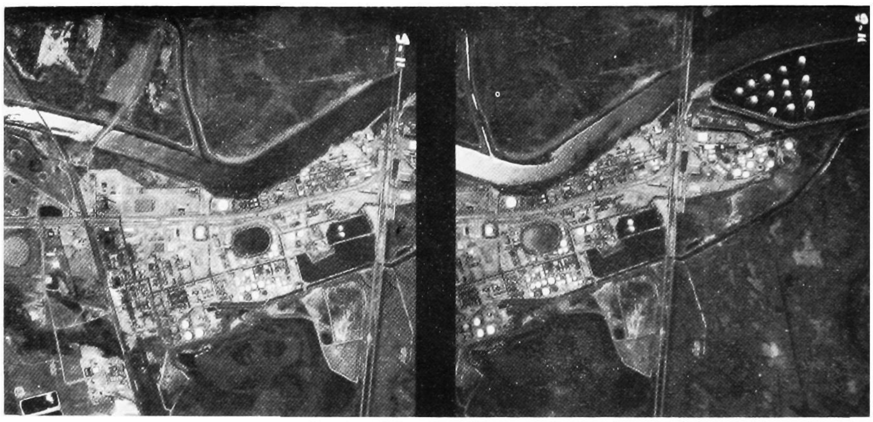


1/10,000, Color/1A, August 20, 1971

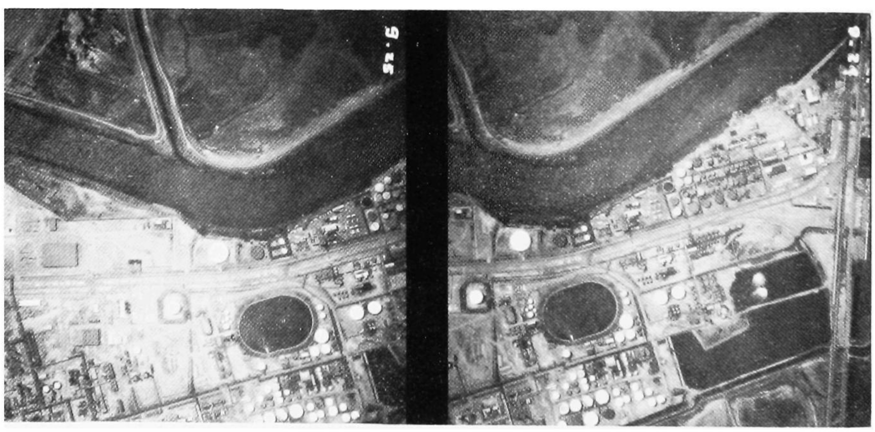
FIGURE 18. OIL DISCHARGE, AVON TEST AREA.



1/80,000

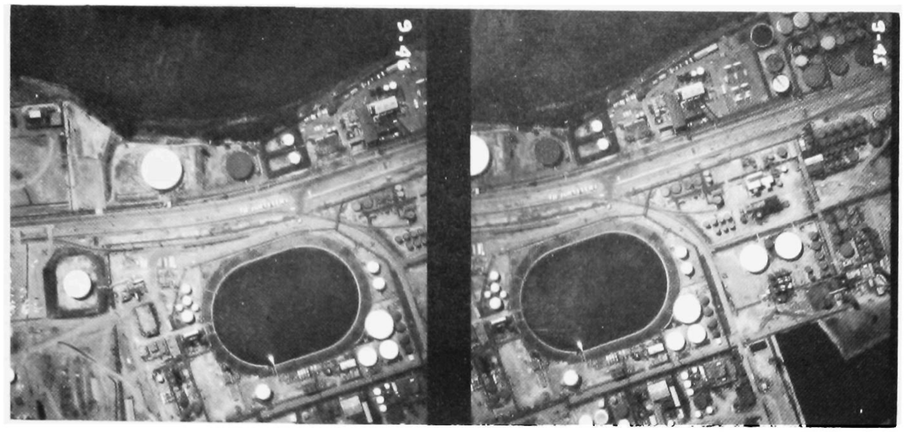


1/40,000

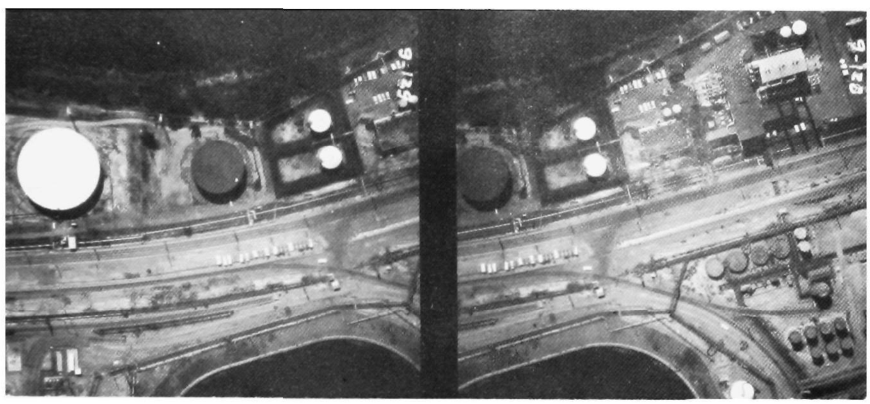


1/20,000

FIGURE 19. AVON TEST AREA. Pan/47B, August 20, 1971



1/10,000



1/5,000

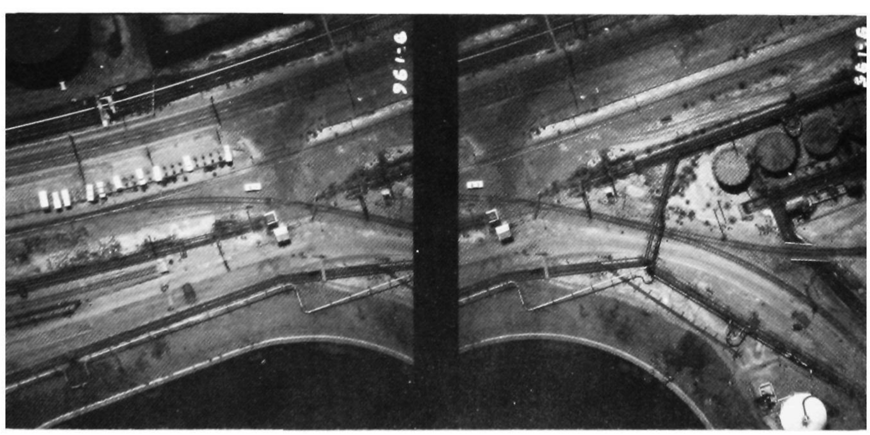
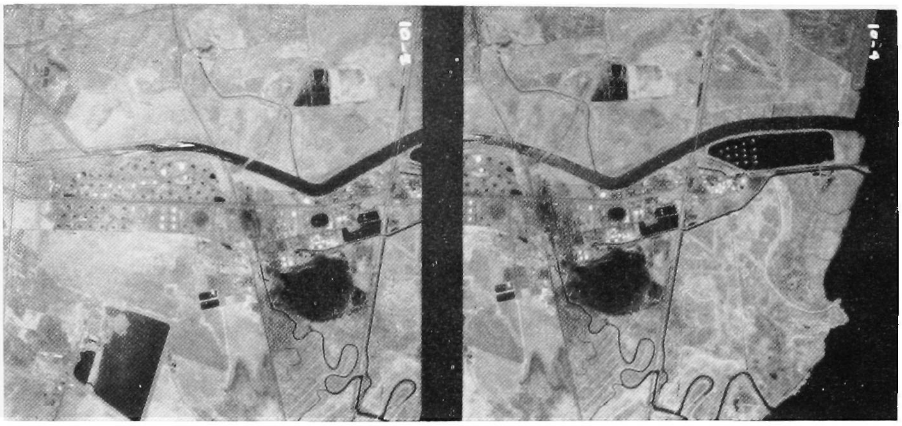
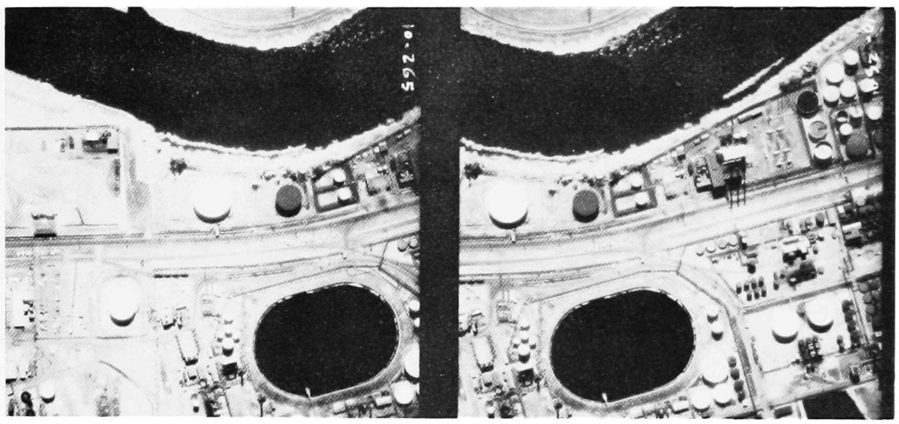


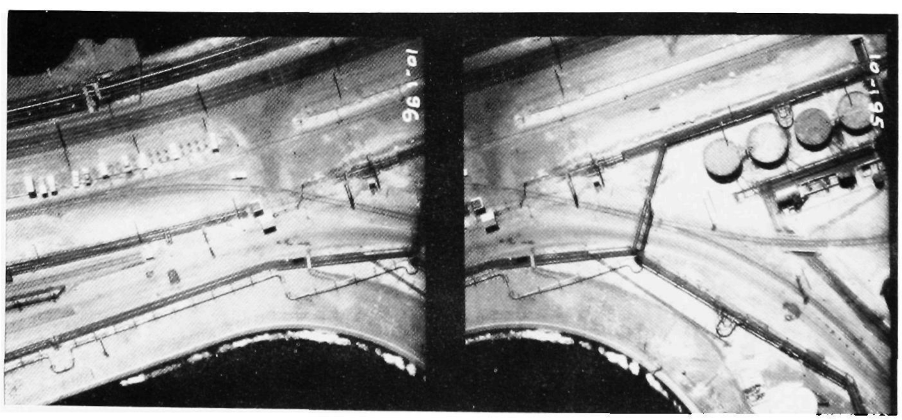
FIGURE 20. SCALE COMPARISON, AVON TEST AREA. Pan/47B, August 20, 1971



1/80,000



1/10,000



1/2,500

FIGURE 21. WATER BOUNDARY DELINEATION, AVON TEST AREA. Black-and-White IR/89B, August 20, 1971

with most shoreline features (such as sand, vegetation, and rocks), which image light in tone. For evaluation of industrial facilities, B&W IR/89B has some limitations. Image sharpness is somewhat limited, tonal contrast between structures may be reduced, and shadow areas are very dark, all of which may obscure important detail. The photographs in this figure should be compared with those in Figures 12-16, 19, and 20.

The use of color IR/12 photography for vegetation studies has received wide acceptance in the fields of agriculture, forestry, rangeland management, and aquatic studies. This "false color" film displays features with a high solar infrared (700-900 nanometers) reflectance as various shades of pink or red, depending on the intensity of the reflectance. Healthy vegetation has a high infrared reflectance, thus its red coloration. Dead vegetation does not appear red on such photographs because of its low infrared reflectance. In aquatic studies, submerged vegetation will not appear red because of the absorption of infrared energy by overlying water.

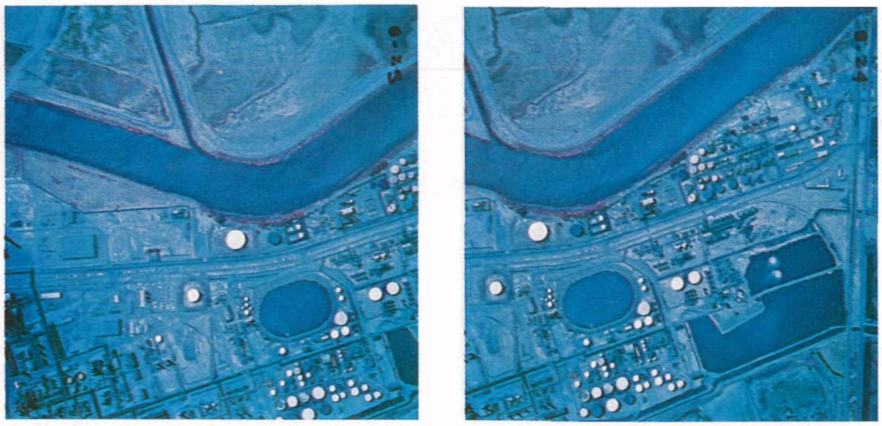
In Figure 22, living vegetation along the creek banks and at various other points appears red. Dead vegetation, such as on levee banks and in open fields, appears blue or tan. This should be compared with previous photographs to evaluate the appearance of various features of interest.

The thermal infrared (8-14 micrometers) images in Figures 23A and 23B were taken over the refinery at the Avon test area from 5,000 feet at about 2300 PDT. Warmer water (light toned) in Pacheco Creek, starting at "A" on Figure 23A, has been imaged, as have cold areas (dark toned) such as the covered reservoir at "B" and the wet meadow at "C". Most significantly, the overflow pond seen in Figures 17 and 18 is at "D" and exhibits a high emissivity (light in tone), characteristic of oil on water.

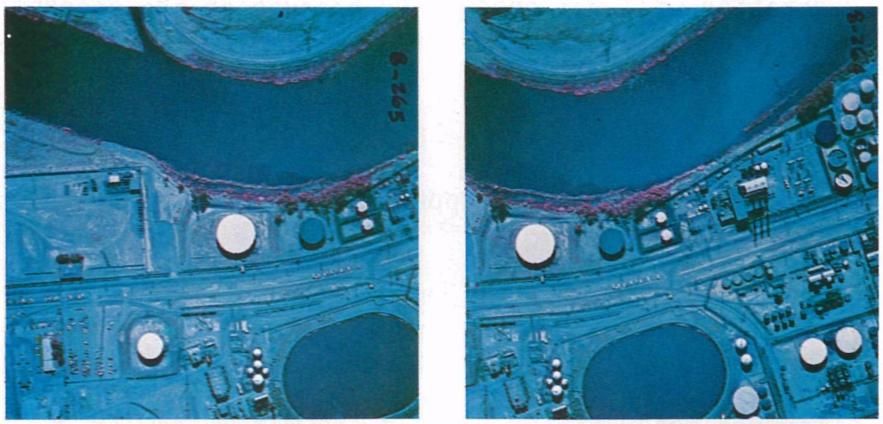
The refinery facilities previously detailed can be seen in Figure 23B. The oil separator pond is visible at "E", heated water in the canal at "F", and heated water being discharged at "G". These images should be compared with previous figures for analysis of features seen in this area.

The black-and-white stereogram in Figure 24 is at a scale of 1/80,000 and is typical of the type of photography available from existing sources, in this case the USGS. The Martinez refinery is at "A", the Benecia - Martinez bridge at "B", the Avon refinery at "C", and the chemical plant at Nichols at "D".

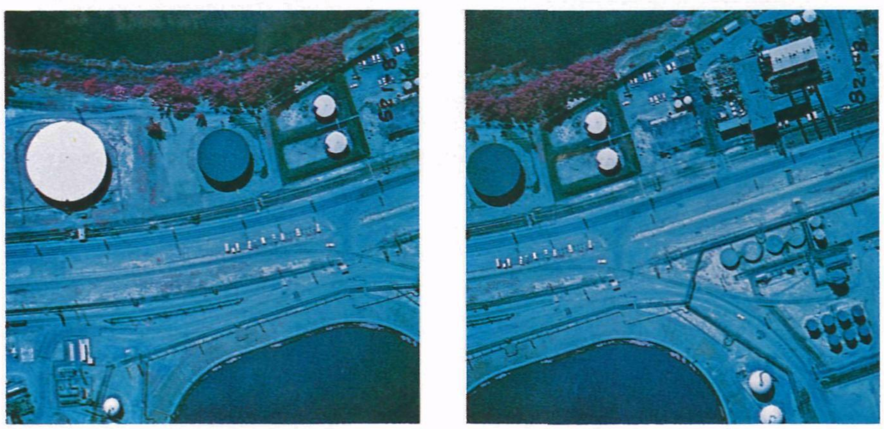
This stereogram should be compared with the 1/80,000 scale photographs in Figures 12, 13, and 19. It will be noted that many features of interest previously described can be seen in this figure, but since color photographs provide information not available from black-and-white photographs (colors of water bodies, vegetation, soils, buildings, etc.),



1/20,000



1/10,000



1/5,000

FIGURE 22. VEGETATION ANALYSIS, AVON TEST AREA. Color IR/12, August 20, 1971

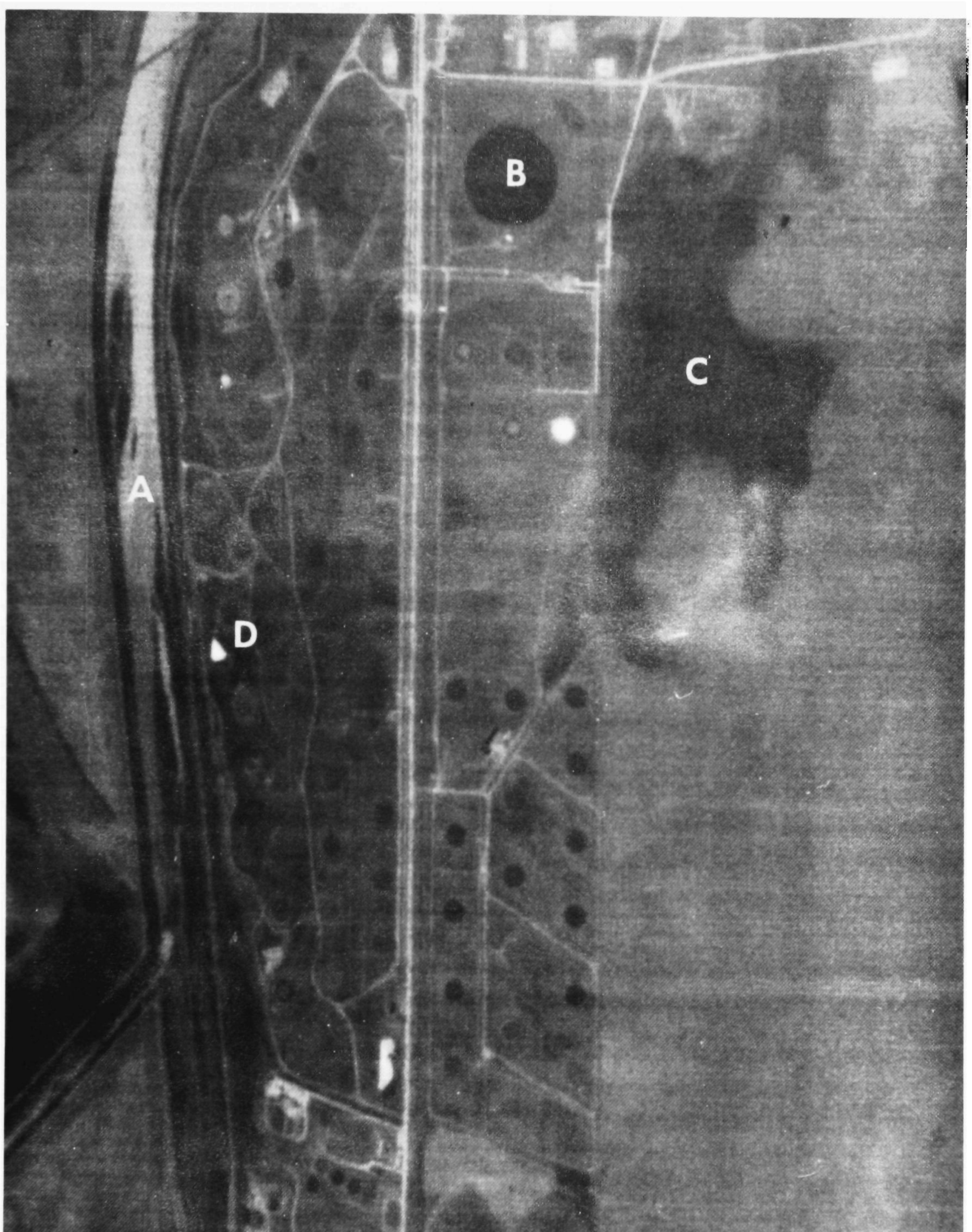


FIGURE 23A. THERMOGRAM, AVON TEST AREA. 2306 PDT, August 9, 1971 at 5,000 feet

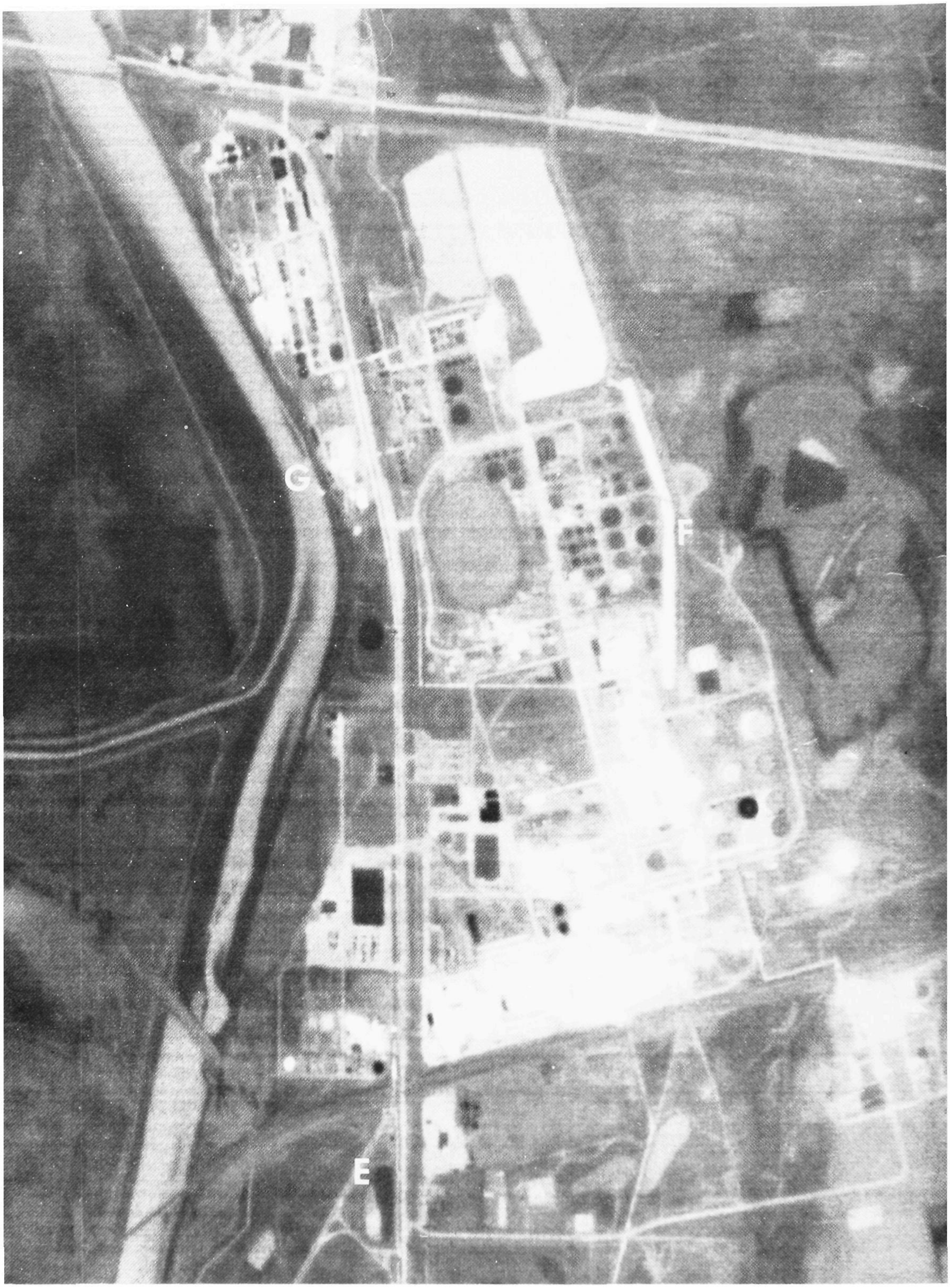


FIGURE 23B. THERMOGRAM, AVON TEST AREA. 2306 PDT, August 9, 1971 at 5,000 feet

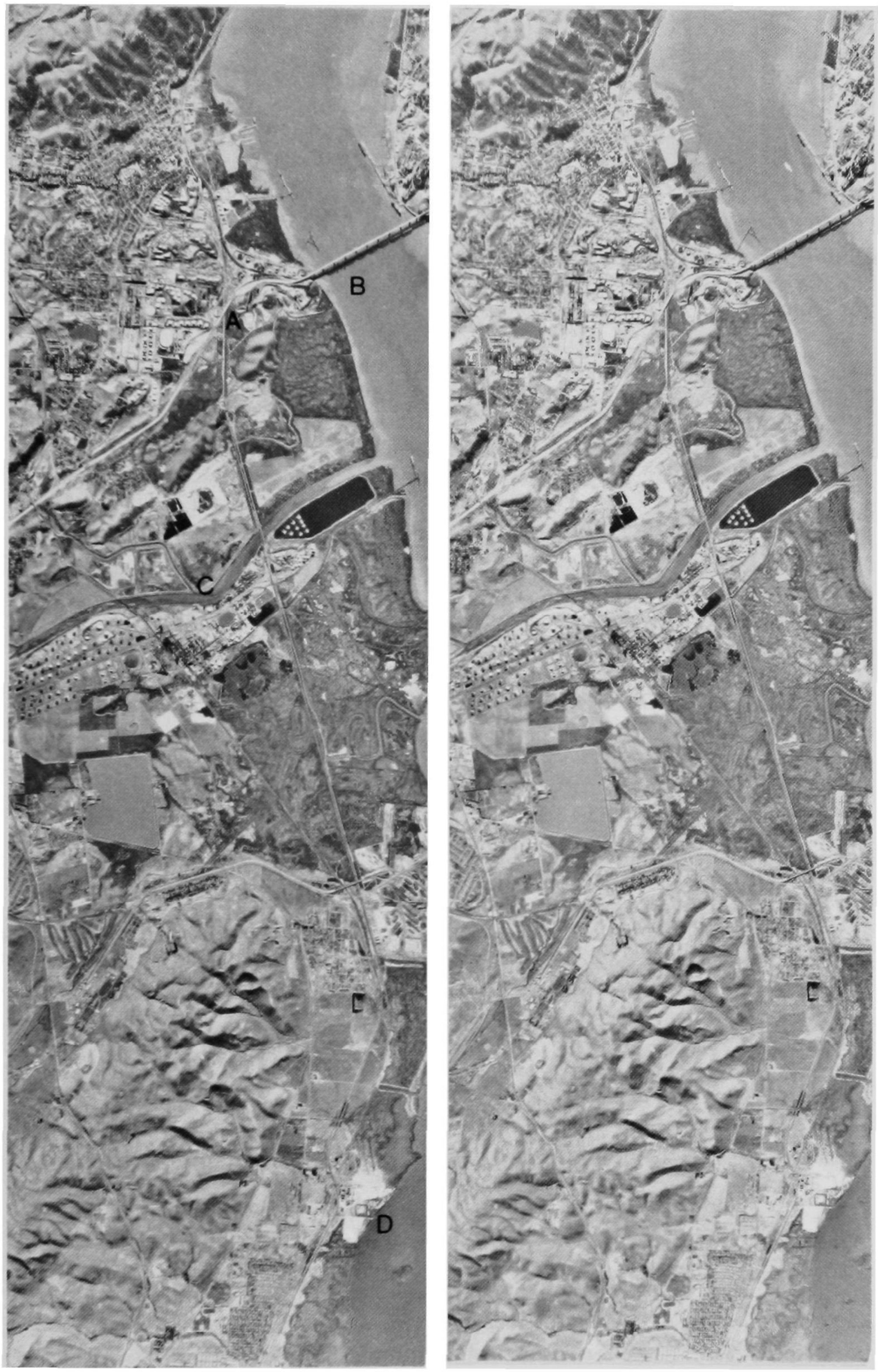


FIGURE 24. NICHOLS-AVON-MARTINEZ. 1/80,000, Panchromatic, May 14, 1970 by USGS

the use of the latter allows fewer judgements regarding potential spill sources. When comparing other figures of the same area with this one, it should be recognized that some of the variations are due to differences in dates of photography.

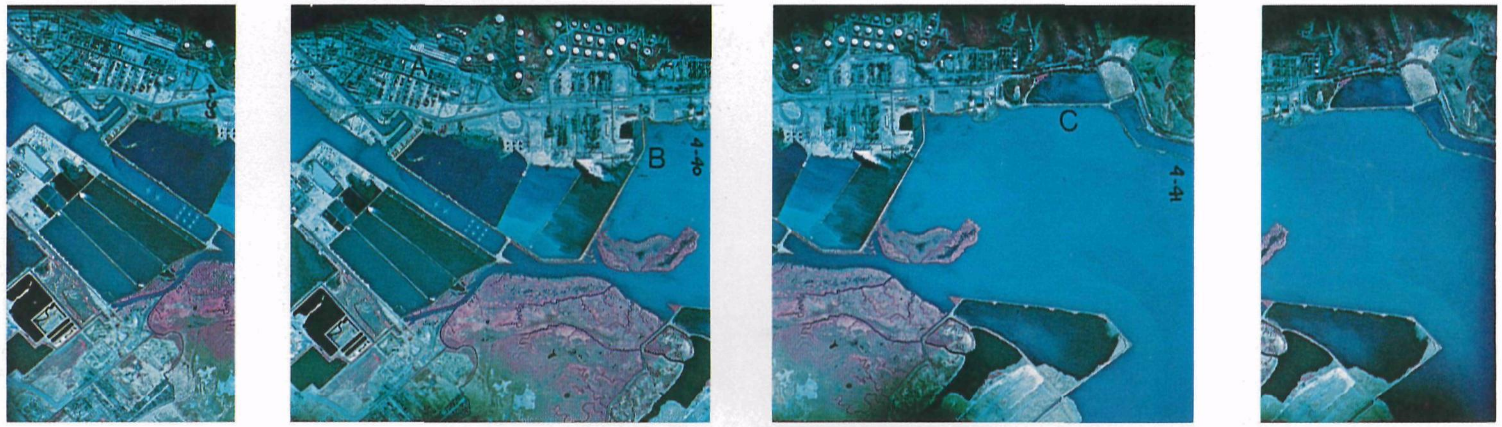
The upper stereogram in Figure 25 at 1/40,000 scale shows a refinery at Richmond, with waste water holding ponds, refinery facilities at "A", and storage tanks at the top of the strip. Waste materials are being discharged into the San Francisco Bay at "B". A large scale stereogram of the waterfront at "B" is shown in the lower right and in the oblique view at lower left.

The waste discharge at "B" was detected on the small scale (1/40,000) photographs before the flight line for large scale coverage was selected. This is a typical example of the way in which a spill prevention survey should be conducted. The preferred sequence is to obtain small scale coverage, interpret that photography making the necessary judgements regarding areas of interest for further study, locate large scale flight lines, and acquire large scale coverage. Interpretations can then be made relative to the potential spill threat by a careful evaluation of the levees, drainage ditches, holding facilities, waste piles, and adjacent waterfronts. The storage pond at "C" is contained in Figures 26 and 30-32. An oil separation facility can be seen at "D" in the lower stereogram and a patch of floating oil at "E".

The image in Figure 26 is from a thermal infrared scanner operating in the 8-14 micrometer range. As before, the tonal values represent various surface temperatures, light-toned features being hot and dark-toned features being cold. This line was flown at 10,000 feet at 0100 PDT over the Richmond refinery area. Water ponds at higher than ambient temperature are visible at "A", and both hot and cold storage tanks are clustered at "B". The cooling pond at "C" is the one seen in Figure 25 at "C". In this thermogram, a discharge of heated effluent is apparent which was not visible on the corresponding photography. This image should be compared with the images in Figure 25 and 27-32.

Storage tanks exhibit various emission characteristics, depending on the temperature of the fluid contained in the tank, the volume of the fluid contained in the tank (and thus empty space above the fluid), and the material from which the tank roof is fabricated or covered (painted or bare metal, asphalt, wood, etc.). It is therefore misleading to conclude that the tonal value of the tank top image reveals something about the volume of fluid in the tank. However, an oblique view, in which the side of a tank is visible, will give some indication of the volume of material stored in the tank, provided a temperature difference can be recorded by the thermal scanner. The tanks located at "A" in Figure 27 exemplify these features. The waste discharge point at "B" in this figure may also be seen in Figure 25, also at "B". Individual vents of cooling towers are visible at "C", and an oil separator is visible at "D". This thermal infrared image was taken from 1,500 feet at about 0100 PDT over the Richmond refinery area.

FIGURE 25. OIL REFINERY WASTE, RICHMOND TEST AREA.



1/40,000, Color IR/12, July 27, 1971

Color/1A, November 5, 1971

1/10,000, Color/1A, September 9, 1971

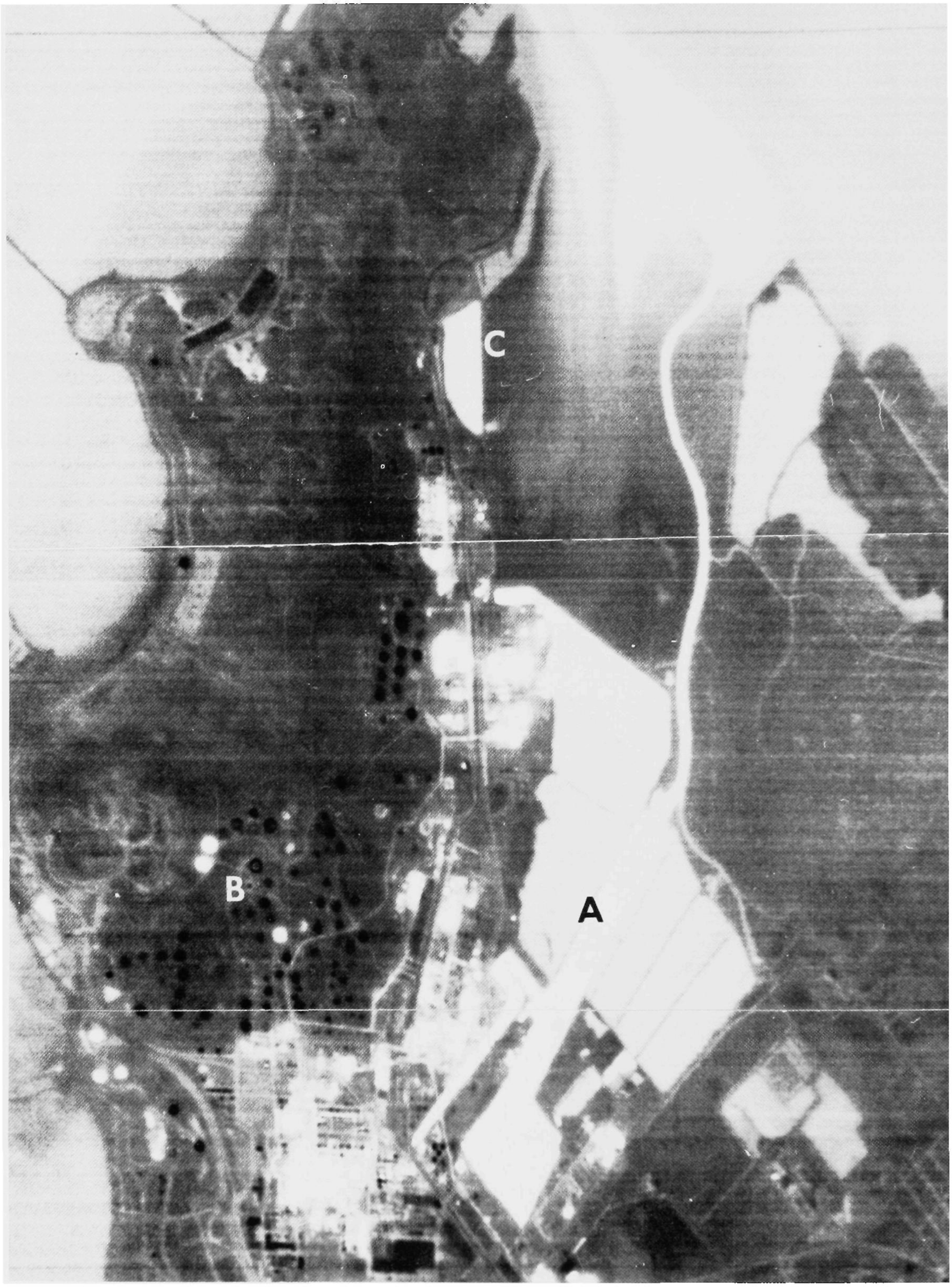


FIGURE 26. THERMOGRAM, RICHMOND TEST AREA. 0100 PDT, August 15, 1971 at 10,000 feet

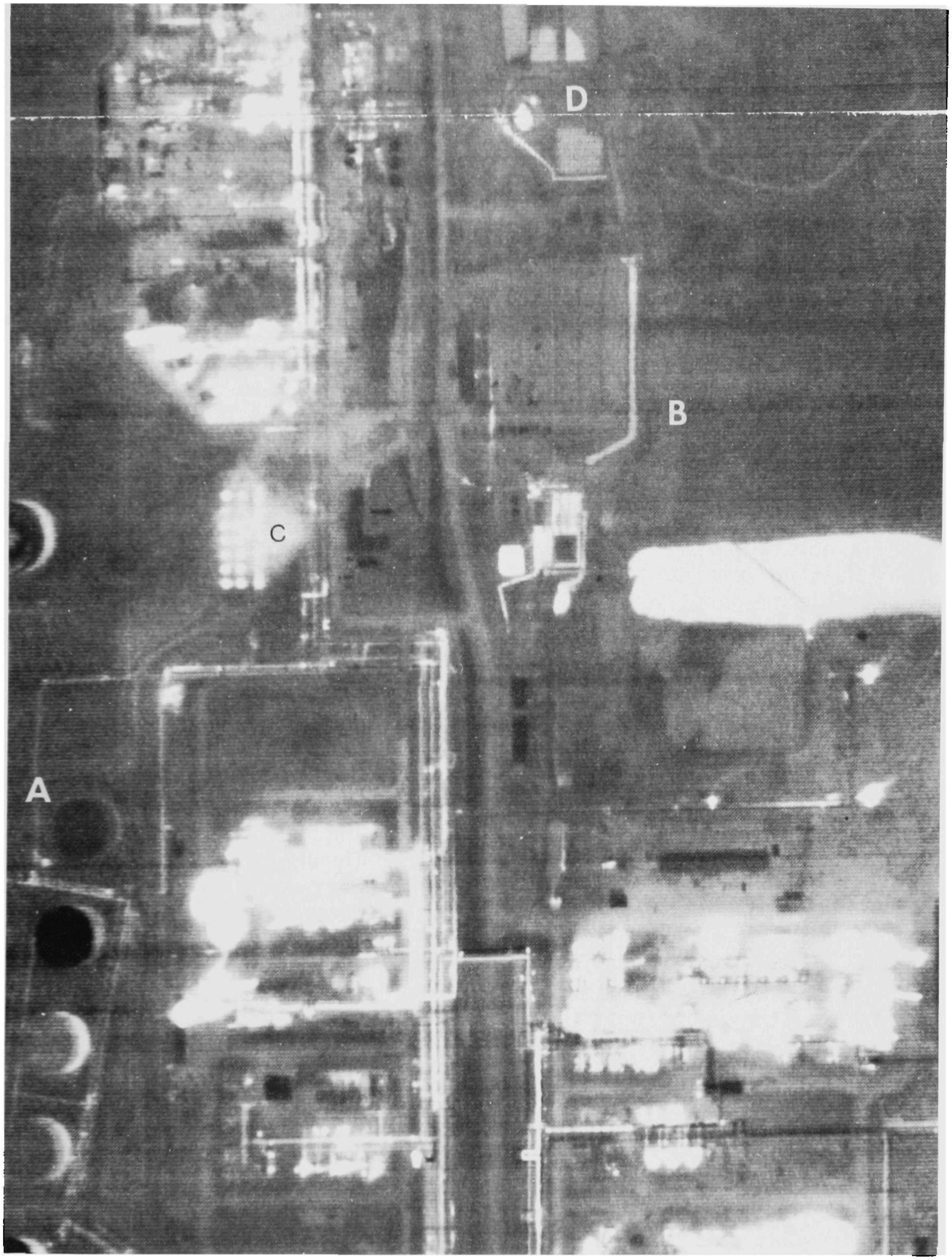


FIGURE 27. THERMOGRAM, RICHMOND TEST AREA. 0048 PDT, August 15, 1971 at 1,500 feet

Figure 28 is a thermal infrared image of a refinery at the Richmond test area, taken at about midnight from 5,000 feet. The main discharge point from the holding pond at "A" can be seen, as well as seepage of warm water along the levee. A dispersion of warm water into San Francisco Bay is visible at "B". Thermal imagery taken at about midnight or somewhat later usually provides very useful information on surface temperatures and emission characteristics.

The thermal infrared image in Figure 29 was taken from 1,500 feet at about 0100 PDT, the subject being the same holding pond in the preceding thermal image. At this scale, it is possible to see clearly the main discharge from the pond, as well as several heated water seepage points along the levee. This should be compared with thermal images taken at 10,000 and 5,000 feet in Figures 26 and 28, respectively, as well as with Figure 32, which shows color aerial photographs of the holding pond.

Figure 30 is a thermal infrared image of the Richmond refinery area from 5,000 feet taken at about 2200 PDT. Some recognizable features can be seen on this image, even though imagery acquired in early nighttime is not the most desirable. Some surface emission from daytime solar heating remains during pre-midnight hours and usually results in undesirable imagery; post-midnight hours are therefore recommended for thermal infrared flights. Storage tanks are located at "A", a cooling point at "B", warm water drainage from a refinery at "C", and a pleasure boat harbor at "D".

Figure 31 is a daytime thermal infrared image of the Richmond area, taken at 5,000 feet at about 1600 PDT. In order to record detail on the land areas, it was necessary to adjust the scanner to record the water areas as black (cold). In reality, the water temperature difference between night and day was slight, while the land temperature difference between night and day was as much as 30°F. The holding pond at "A" is seen to exhibit the same tonal value as the bay water; thus, the seepage detected at night on thermal imagery is not detectable here (however, tidal differences were probably a factor as well). One might also be tempted to conclude that both the bay and the pond were at the same temperature, which is most certainly not the case. This ambiguity arose because the thermal scanner was deliberately "tuned" to record <u>land</u> emissivity data and not <u>water</u> data. The temperature difference between land and water may be a few degrees late at night, while, in the daytime, it may be 20 degrees or more. Because the land cools so rapidly after sunset, thermal imagery taken late at night can usually record emissivity information over both land and water areas without losing detail in either one. This can only rarely be accomplished during daylight or early evening hours. Figures 31, 30, and 29 should be compared, noting the contrasts from daylight to midnight.

By comparing the thermal infrared images in these figures with the color photographs of the same area, one can evaluate the utility of thermal infrared images in spill prevention surveillance. It is suggested that thermal infrared imagery is useful only where features of interest are

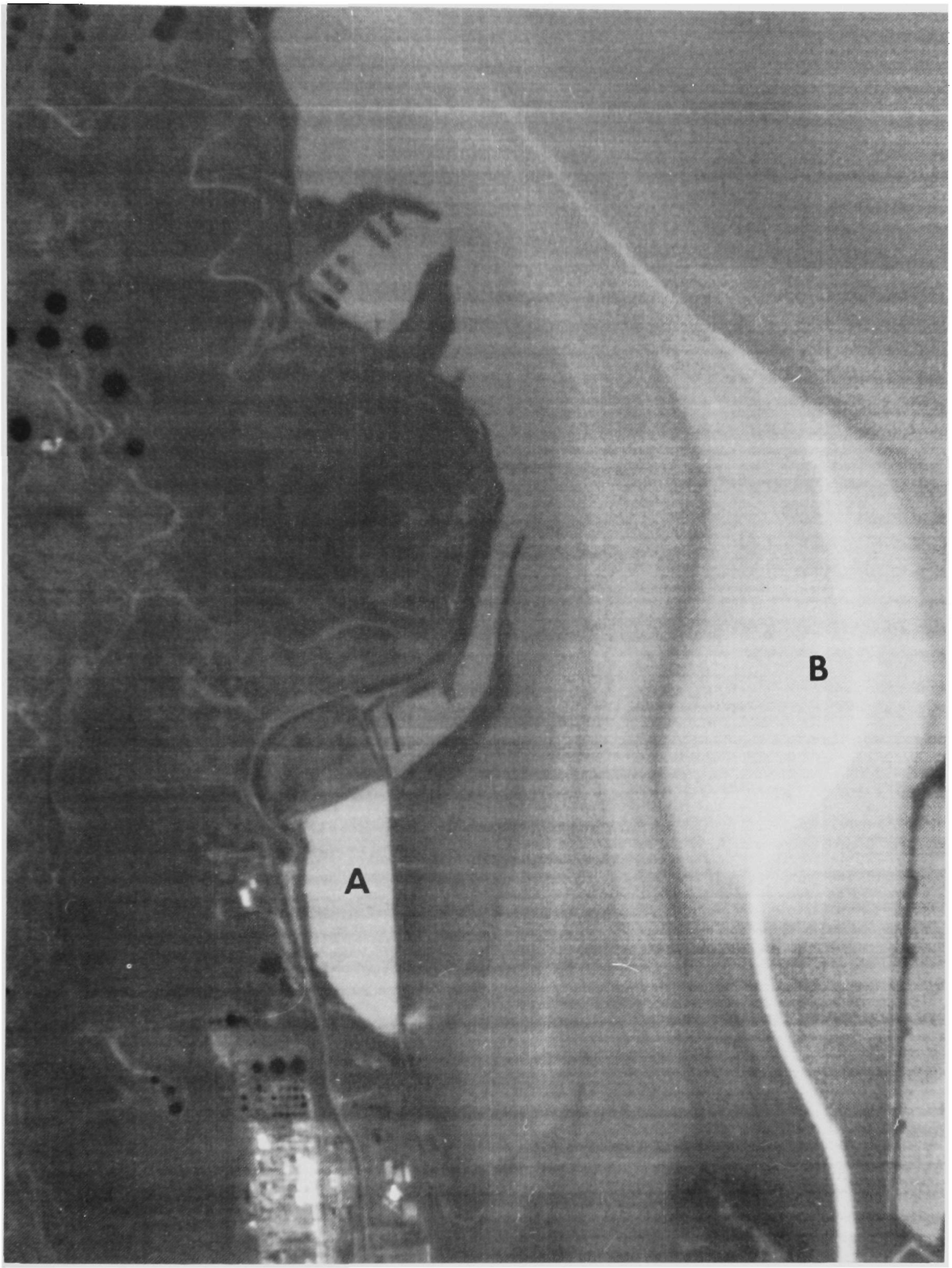


FIGURE 28. THERMOGRAM, RICHMOND TEST AREA. 0012 PDT, August 15, 1971 at 5,000 feet

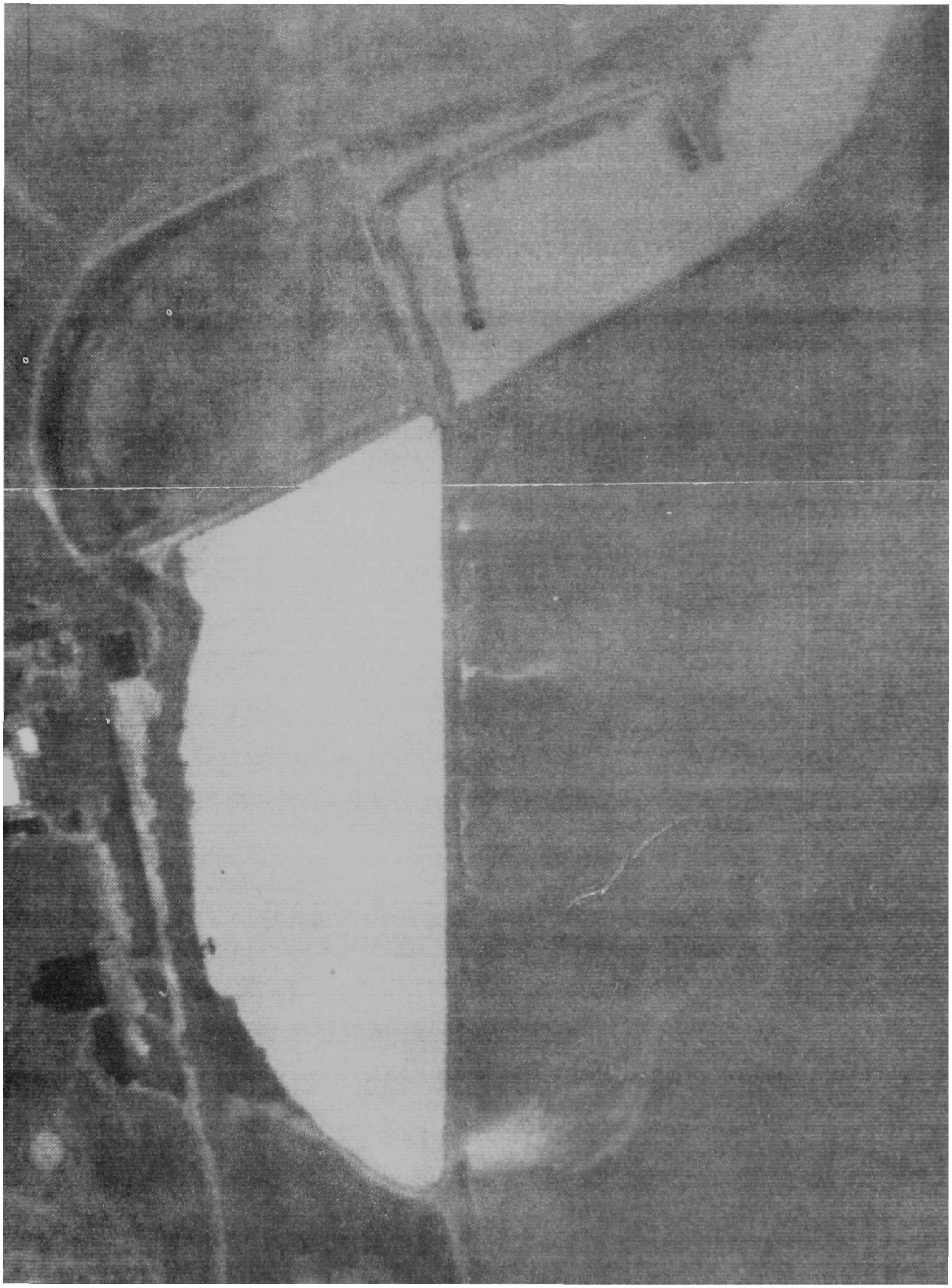


FIGURE 29. THERMOGRAM, RICHMOND TEST AREA. 0048 PDT, August 15, 1971 at 1,500 feet

FIGURE 30. THERMOGRAM, RICHMOND TEST AREA. 2207 PDT, August 9, 1971 at 5,000 feet

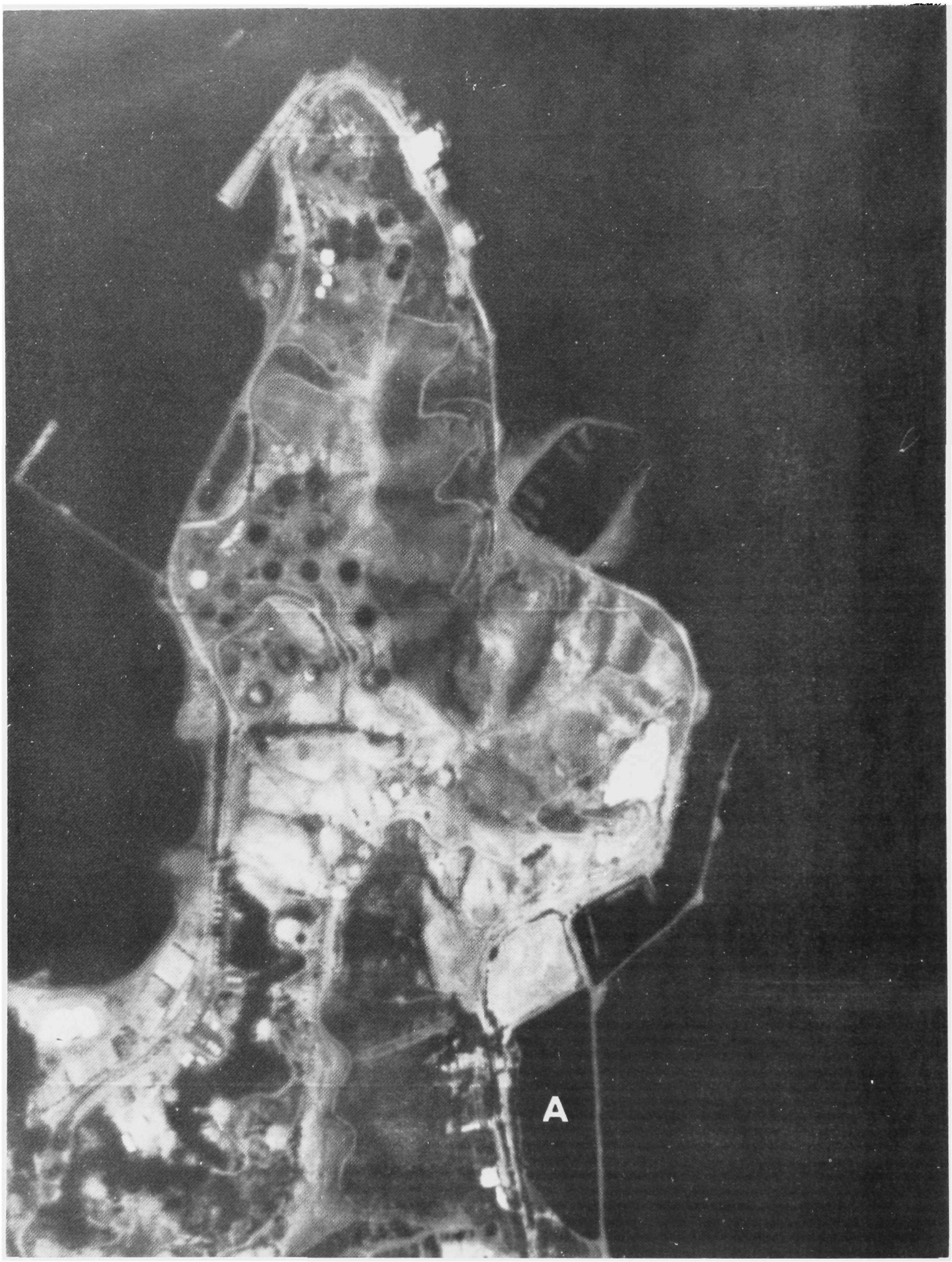


FIGURE 31. THERMOGRAM, RICHMOND TEST AREA. 1557 PDT, August 9, 1971 at 5,000 feet

visible as a function of their temperature or thermal emission difference. The imagery presented demonstrates that, for purposes of spill prevention, unique information rarely occurs on thermal imagery.

The stereo photographs at the top of Figure 32 were taken to permit detailed evaluation of the levee condition and the drainage seen on the thermal images. On the low altitude oblique photograph at lower left, a drain pipe can be seen passing through the levee at "A".

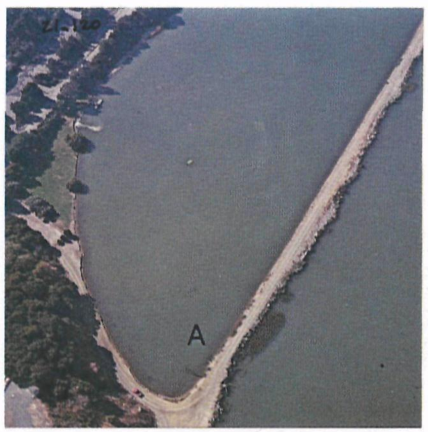
The color photographs in the lower right part of this figure were taken of a color television display produced by an image enhancement device (International Imaging Systems, Digicol). With this device it is possible to "contour" density difference by assigning a unique color to each density, thus making a multicolor display from a black-and-white image. A technique called "density slicing" permits the operator to measure the relative areas of the various densities automatically by adjusting the gain setting. The relative areas portrayed on the imagery for a particular water temperature can be determined by this device, which aids in monitoring the dispersion of heated effluent into a body of water. The holding pond seen in the previous imagery is displayed as a yellow or greenish-yellow feature in these images, which were created electronically from the images in Figures 26 and 29.

Figure 33 illustrates a waterfront with several potential spill sources. The upper photographs were taken at a scale of 1/40,000 for a regional survey of the Richmond area, using color IR/12 photography. An oil catch basin holding heavy oil waste from tanker bilges can be seen at "A". The basin is seen on color film, at a scale of 1/10,000, in the center strip of photographs. It is also possible to see dark stains along the shoreline of the pond and containers adjacent to the pond. An oil separation facility is located at "B"; this feature is difficult to identify on the small scale coverage. At "C" are stored materials awaiting transport. The two photographs in the lower row, one in color and one in black-and-white, provide a means for comparing the usefulness of each type of oblique photography. The two photographs are mounted for stereoscopic viewing to facilitate comparison. By alternately blinking his eyes while viewing in stereo, the observer can make meaningful comparison.

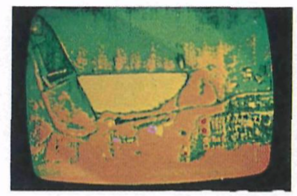
A steel salvage operation at Richmond is seen in Figure 34 at "A". A cluster of tanks can be seen at "B" and at several other locations in this area. A manufacturing plant with some shoreline residue visible is at "C". Disposal practices near the shoreline are visible in the center and lower photographs. The vessel in the pond behind the earthen dam is surrounded by an oil slick. The black-and-white photograph is included for comparison of information obtainable from both color and black-and-white photographs. Oblique photographs, such as those in the lower part of this figure which show scrap steel and associated materials, are very useful for evaluating potential spill hazards. Use of low altitude oblique photographs may eliminate the need for a time-consuming ground visit.

FIGURE 32. HOLDING POND, RICHMOND TEST AREA.

1/10,000, Color/1A, August 20, 1971



Color/1A, October 5, 1971



0012 PDT, August 15, 1971 at 5,000 feet

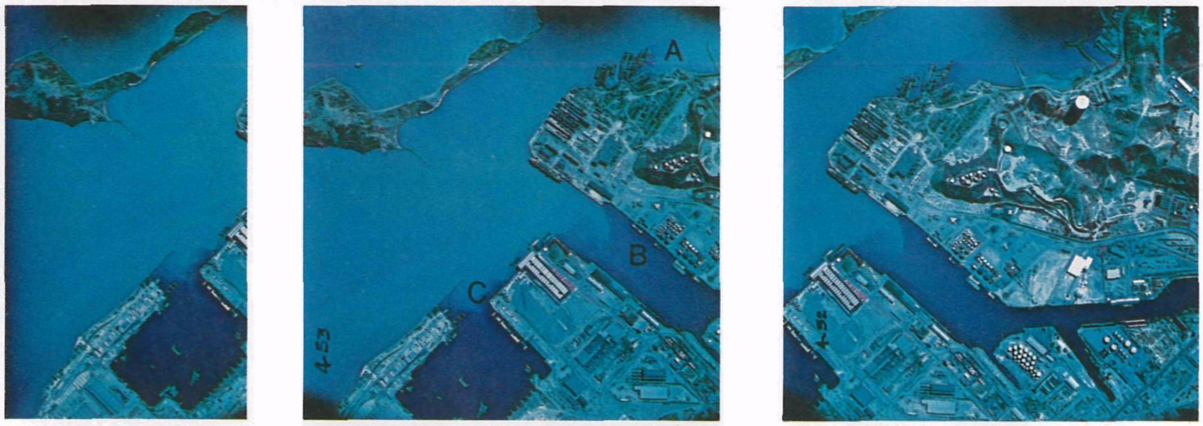
0048 PDT, August 15, 1971 at 1,500 feet

1/40,000, Color IR/12, July 27, 1971

1/10,000, Color/1A, September 9, 1971

Color/1A, November 5, 1971

FIGURE 33. OIL WASTE POND, RICHMOND TEST AREA.



1/40,000, Color IR/12, July 27, 1971

1/10,000, Color/1A, September 9, 1971

Pan/47B, September 17, 1971 Color/1A, September 17, 1971

FIGURE 34. STEEL SALVAGE, RICHMOND TEST AREA.

Figure 35 shows industrial and mining activities. The upper photographs were taken of the manufacturing plant producing prefabricated concrete products, seen at "C" in Figure 34. Residual material is piled along the shoreline. The center photograph shows a rock quarry at the Richmond test area at "A". Storage tanks are clustered on the hill. Trucks and earth-moving equipment can be seen in the parking area in the lower stereogram at "B".

Figure 36, of the Oakland Estuary area, illustrates an area with high shoreline utilization, where both polluting and non-polluting operations are collocated. The color IR/12 stereogram was used for an initial survey to select features of interest. A steel salvage operation is visible at "A", with residue piles and storage tanks at the water's edge. There is a containerized cargo transshipment point at "B", ship loading cranes are also visible. Natural gas storage tanks are located at "C" and a railroad yard at "D".

The color/1A stereogram in the center shows, at larger scale, the steel salvage operation visible at "A" on the small scale color IR/12 photographs. Adjacent to the salvage operations is a small chemical plant at "E". The tanks at "F" are abandoned (this fact was determined by ground checking and could not be determined by photographic interpretation). A residue pile extending into the water is visible at "G".

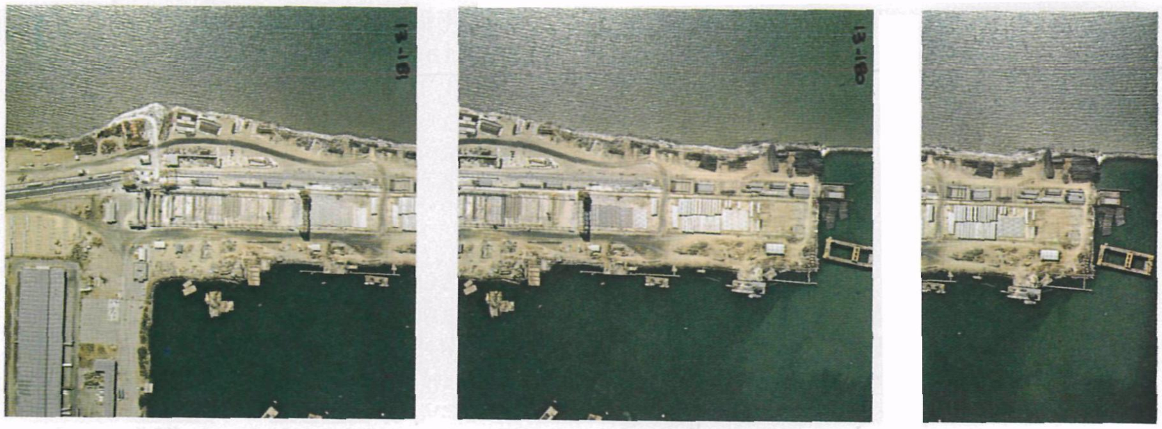
The oblique photographs at the lower left of Figure 36 are useful for detailed interpretation of industrial activities. The ground view shows the residue pile at "G" and adjacent abandoned tanks.

The sequence of photographs in Figure 37 shows a copper ore residue (roasted pyrite) pile, first observed and photographed on a reconnaissance flight. The small scale color IR/12 photographs at upper right reveal the residue pile and a color discharge into the water at "A". An oil refinery can be seen at upper right, with ship-loading docks at "B".

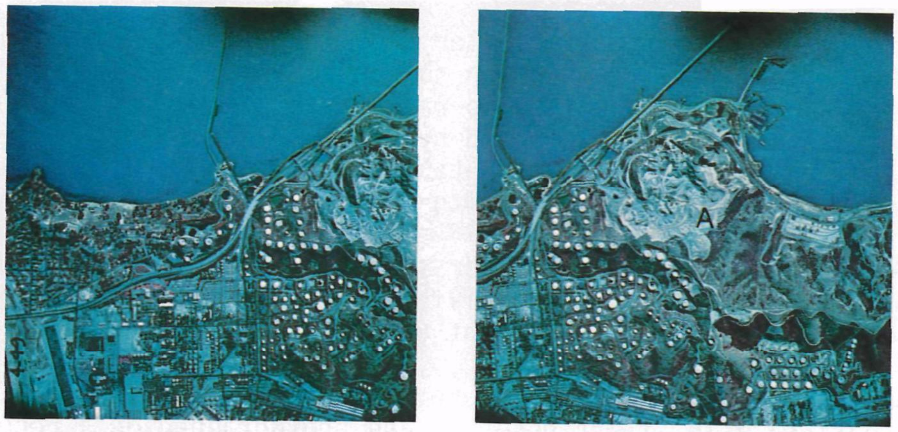
The lower photographs were taken at later dates and show removal of the residue pile from the shoreline. The lower right photograph is a ground view of the residue pile at the waterfront, taken after removal had begun. This type of photographic presentation has been used to illustrate the sequence of corrective measures following enforcement actions. In this case, corrective measures followed issuance of a Cease and Desist Order by the California Water Resource Control Board.

Figure 38 illustrates a chemical plant and associated waste disposal facilities ("A") for manufacture of alum, various acids, ammonium hydroxide, and other products, as determined by interview with plant personnel. The waste material is slurried lime, used to neutralize the by-products. The oblique photographs in the center show the residue holding areas and dikes.

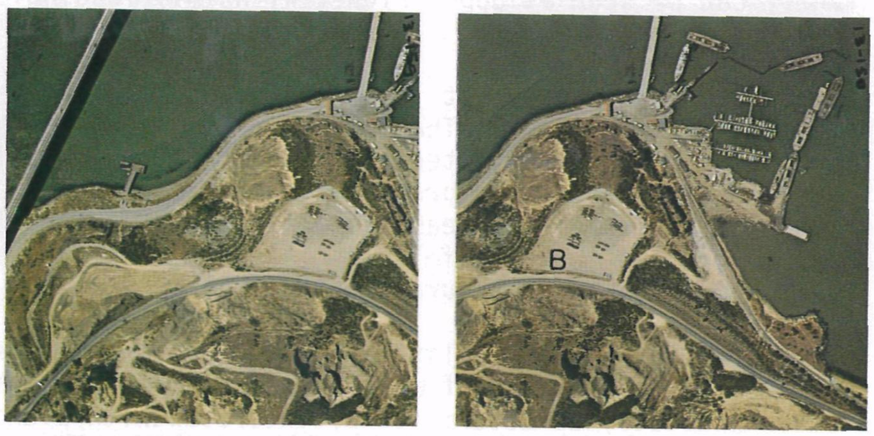
The large scale photographs at the bottom show the area in more detail and reveal a point where the levee is very narrow ("B"), a condition



1/10,000, Color/1A, September 9, 1971

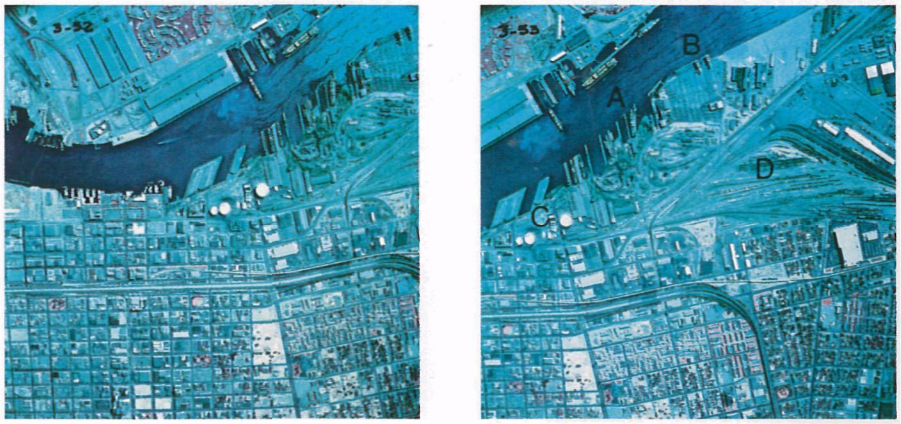


1/40,000, Color IR/12, July 27, 1971



1/10,000, Color/1A, September 9, 1971

FIGURE 35. INDUSTRIAL AND MINING OPERATIONS, RICHMOND TEST AREA.



1/40,000, Color IR/12, July 27, 1971

1/10,000, Color/1A, September 9, 1971

Ektachrome X, September 15, 1971

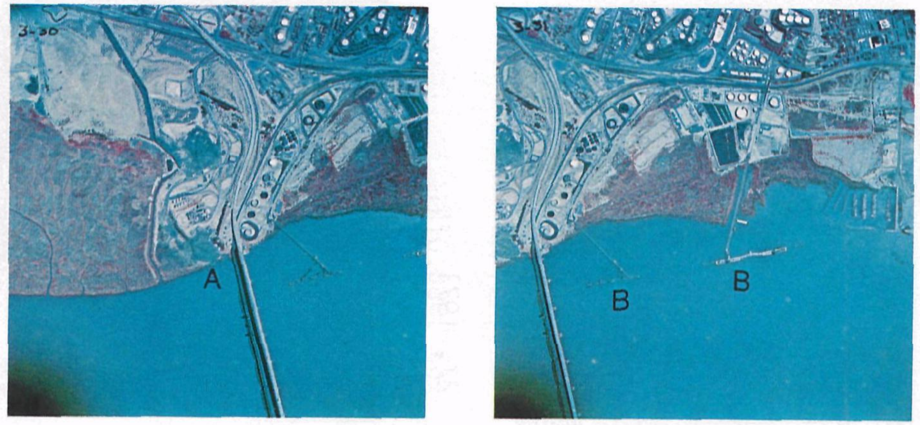
Color/1A, September 13, 1971

Color/1A, July 19, 1971

FIGURE 36. HEAVY INDUSTRY, OAKLAND ESTUARY TEST AREA.

FIGURE 37. RESIDUE PILE, MARTINEZ TEST AREA.

Color/1A, July 19, 1971

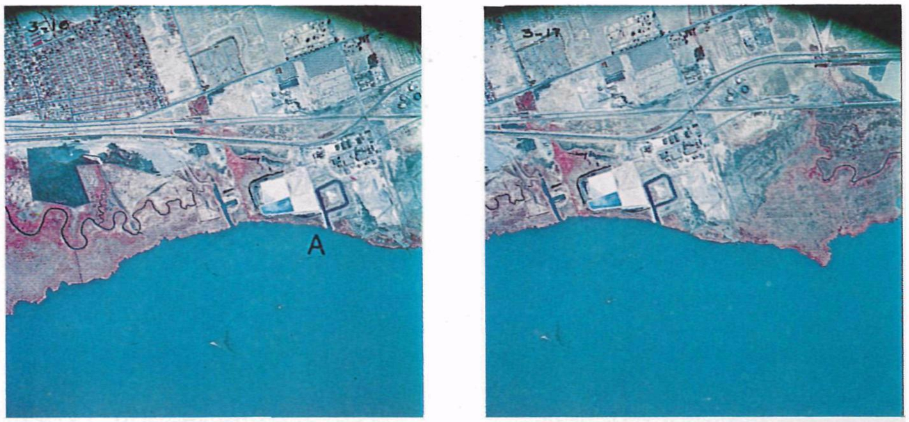


1/40,000, Color IR/12, July 27, 1971

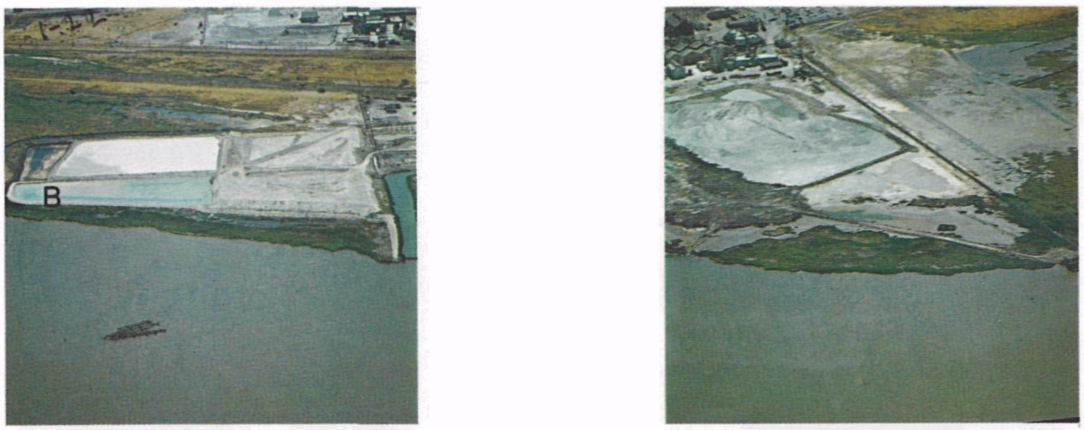
1/10,000, Color/1A,
September 9, 1971

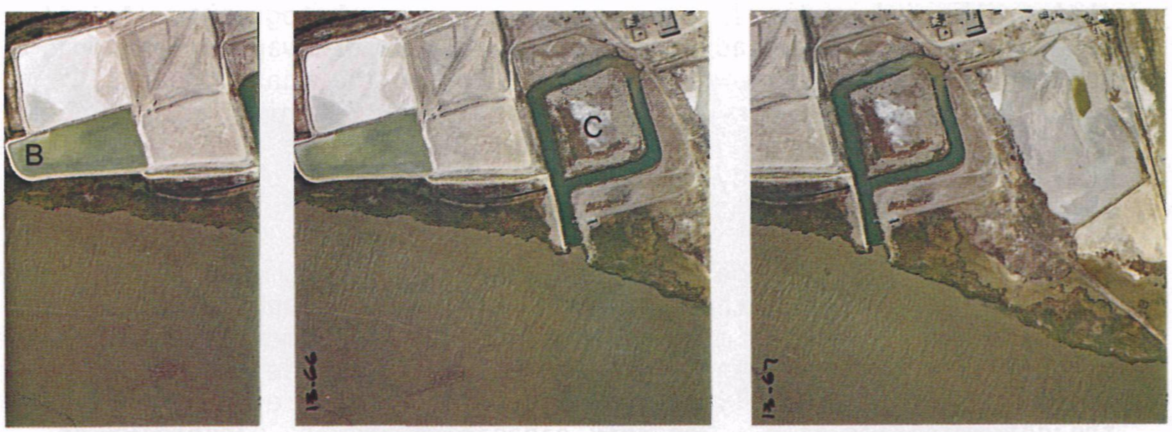
Color/1A, September 13, 1971

Color/1A, September 23, 1971



1/40,000, Color IR/12, July 27, 1971





1/10,000, Color/1A, September 9, 1971

FIGURE 38. CHEMICAL PLANT, NICHOLS TEST AREA.

which might lead to failure and a spill of waste materials. The circular canal at "C" is used to hold cooling water from the chemical manufacturing processes.

Figure 39 presents the recognition characteristics of a fossil fuel power generating plant ("A"). The upper photographs were taken on color IR/12 at a scale of 1/40,000 and demonstrate a problem caused by weather; low clouds over the Hunters Point test area obscure part of the ground scene. An underwater sewage discharge is located at "B".

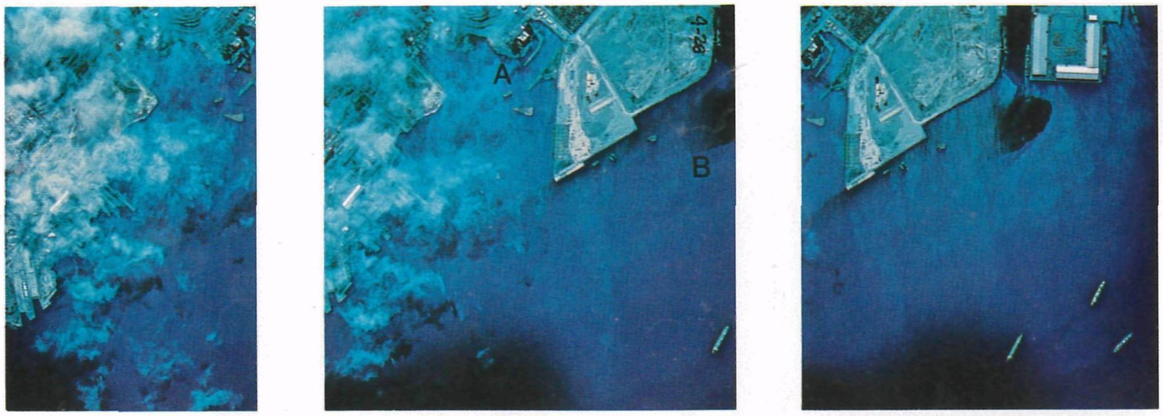
A power generating plant can usually be recognized by the presence of tall vent stacks, nearby fuel storage tanks, cooling water intake and discharge facilities, power transformers, transmission facilities, and the absence of raw material and/or waste piles, large employee parking lots, and finished products stored for transport.

The installation seen in the center and lower photographs of Figure 39 fits these criteria and was correctly identified by photointerpretation. On the center photograph, the wall-like revetments around the four tanks to the rear of the power plant appear to be as tall as the tanks; that this is not the case is difficult to determine on a single photograph, but is strikingly simple in three-dimensional viewing.

The lower stereogram is composed of low altitude oblique photographs. An intake channel with debris from a nearby land fill operation is visible, as is a turbulent cooling water outfall channel.

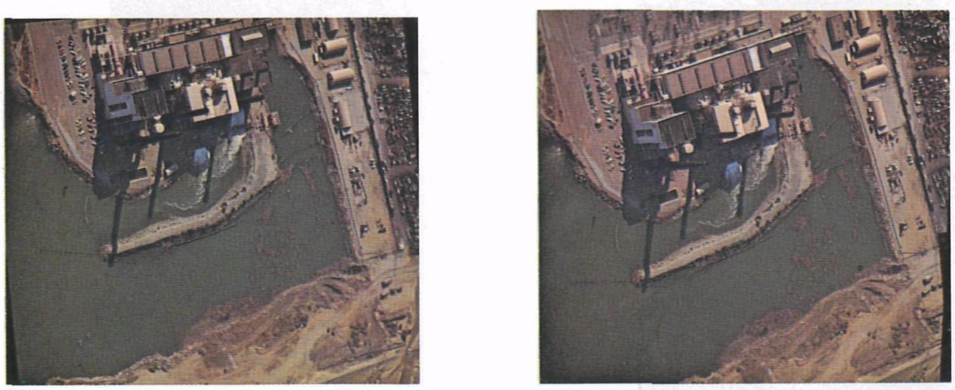
Using the same criteria for power plant identification described in Figure 39 and in the photointerpretation key, the feature seen in Figure 40 was correctly identified by photointerpretation as a fossil fuel power generating plant. This facility, at Pittsburg on the Sacramento River, can be seen at "A" on the 1/40,000 scale color IR/12 photographs and on the 1/10,000 scale color/1A photographs. An oil separator pond and two adjacent empty waste water evaporation ponds are apparent at "B", as are water intake pumps on the shoreline at "C", and power transformers at "D". The dark streak in the river at "E" is a discharge from a sewage treatment plant at "F". The appearance of the sewage treatment facility and outfall on the aerial oblique views should be compared with the vertical views.

The capacities of storage tanks and associated revetments was estimated by photogrammetry from these 1/10,000 scale photographs (Table 5) to evaluate the value of simple photogrammetric instruments in mensuration of spill prevention photography. No attempt was made to measure earthen revetments or irregularly shaped objects; the major effort was given to the determination of storage tank capacities and the capability of simple vertical wall revetments, such as those at the power plant site, to retain the contents of the enclosed tanks. Errors in photogrammetric measurements were the result of inability to determine accurately the exact scale of individual frames, parallax in the tube magnifier, coarse graduation of the measuring reticle, and most importantly, human error.



1/40,000, Color IR/12, July 27, 1971

1/10,000, Color/1A, September 9, 1971

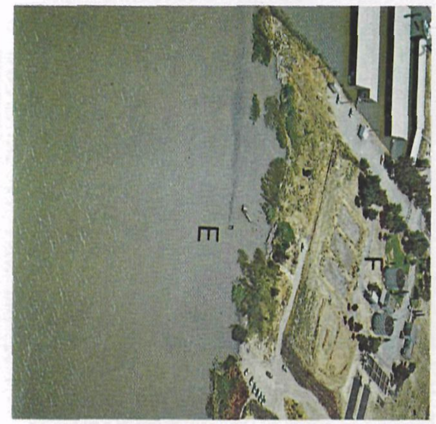


Color/1A, September 13, 1971

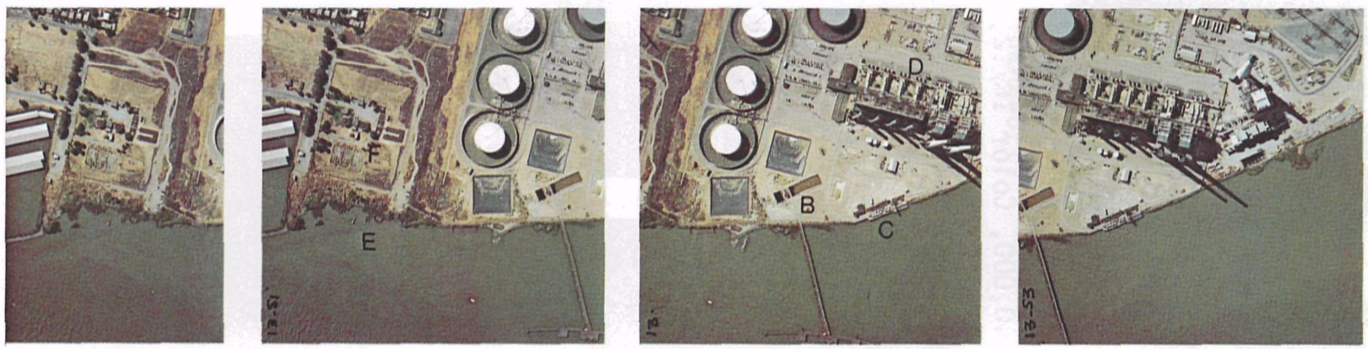
FIGURE 39. POWER PLANT, HUNTERS POINT TEST AREA.

FIGURE 40. POWER PLANT, PITTSBURG TEST AREA.

1/40,000, Color IR/12, July 27, 1971



Color/1A, July 17, 1971



1/10,000, Color/1A, September 9, 1971

Table 5. Photogrammetric Measurements, Avon-Pittsburg

Tank Number (Avon)	Photo Height (Feet)	Photo Diameter (Feet)	Actual Height (Feet)
80-235	33.1	113	41.8
80-231	36.5	113	41.7
Reservoir	--	515	--
55-267	36	112	30
104-217	40	120	54
104-26	51	120	54
15-696	46.2	46.5	47.2
80-517	37	110	41.5
80-2	37	110	42
40-642	44.2	77	48
25-428	28.5	77	29.3
56-209	36.7	97	40
10-214	22.3	54	24
15-391	27	56.5	29.3
7-502	40	34.7	40.4
55-32	33	109	30
25-509	26.6	75	29.5
80-317	34.7	114	41.8
20-133	26.9	65.5	30
315-690	54.5	199	56
66-142	33.4	111	35
PG&E Pittsburg			
Tank	45.3	150	48
Revetment	23.6	285	21.5

film: Color (SO-397), roll #13
scale: 1/10,000
date: September 8-9, 1971

Table 5. (cont.)

Tank Number (Avon)	Actual Diameter (Feet)	Photo Volume (Bbls.)	Actual Volume (Bbls.)	% Error (Volume)
80-235	117.4	60,000	80,000	-25
80-231	117.4	65,000	80,000	-19
Reservoir	515		1,000,000	
55-267	115	65,000	55,000	+18
104-217	120	81,000	104,000	-22
104-26	120	103,000	104,000	-1
15-696	47.5	14,000	15,000	-7
80-517	120	65,000	80,000	-19
80-2	115	65,000	80,000	-19
40-642	80	37,000	40,000	-7.5
25-428	78	22,700	25,000	-9
56-209	100	47,000	56,000	-16
10-214	56	9,000	10,000	-10
15-391	60	11,500	15,000	-23
7-502	36	7,000	7,000	0
55-32	115	55,000	55,000	0
25-509	78	20,000	25,000	-20
80-317	117.4	66,000	80,000	-18
20-133	75.4	15,000	20,000	-25
315-690	200	300,000	315,000	-5
66-142	116.3	58,000	66,000	-12
PG&E Pittsburg				
Tank	160	140,000	168,000	-17
Revetment	299.3	270,000	270,000	0

The use of larger format imagery would greatly reduce such errors; this is especially true because scales are only approximately known from altitude and lens focal length and are most precisely computed where individual frames cover a reasonably large area.

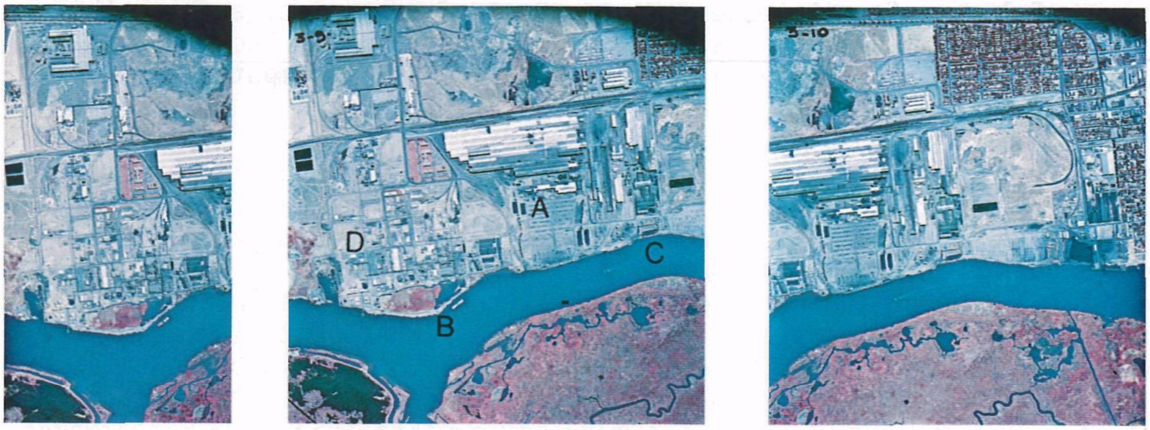
Figure 41 shows a steel mill and nearby waste material holding areas at Pittsburg ("A"). Waste water holding ponds are visible at "B" and "C" on the small scale, 1/40,000, color IR/12 photographs and can also be seen on the larger scale, 1/10,000, color IA photographs at center and lower left. The oblique photograph and stereogram in the lower row show the pond seen at "C" in the center left photographs. Note the chemical plant at "D" in the 1/10,000 scale stereogram. One should be able to see waste water ponds on the photographs in this figure. It should also be seen that very little care is exercised in maintaining the integrity of these waste water basins to prevent uncontrolled spills.

Figure 42 shows a variety of transportation and loading facilities for oil and other petroleum products. The upper photographs show the dock ("A") at the oil refinery at Martinez; pipes are visible on the pier. These photographs should be compared with the pier at "B" on Figure 37. A ship refueling area at Richmond is seen at "B" on the center photographs. Unprotected pipelines connect tanks on the hill with the dock area. The dark materials in the water on the inner side of the pier at "F" could be a small oil spill.

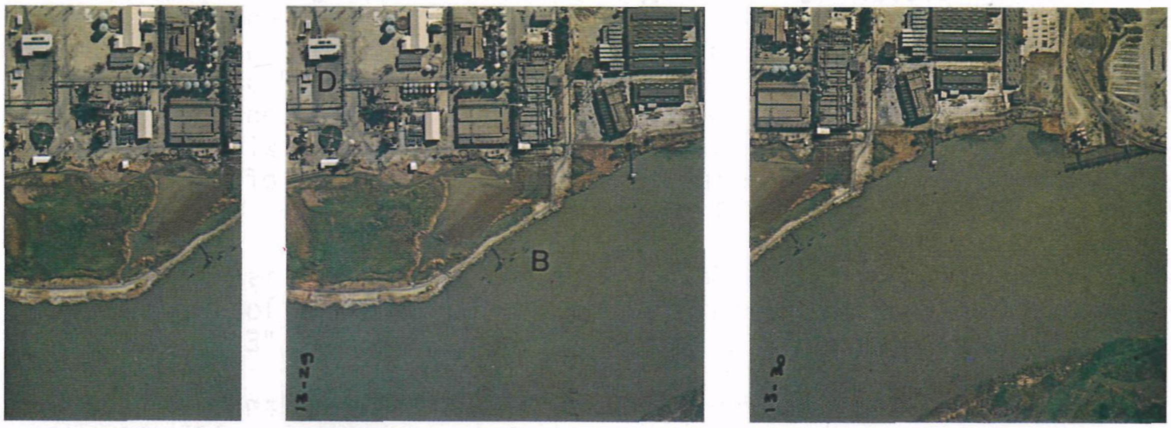
The railcar loading facility for pressurized gas at Avon is seen at "C" on the photograph at the center of this figure. A truck loading facility is at "D", and railcars for oil transport can be seen at "E".

In recognition of the need for a system for classifying land use activities which may present current or potential hazards, a classification plan for spill prevention studies was designed as previously stated. The next logical step was to develop, from the classification plan, an aid to identification by photointerpreters at each level. When structured as a series of pairs of mutually exclusive statements and illustrated with aerial imagery, the plan becomes an image interpreter's key, to be used by persons not necessarily familiar with the varied activities and processes encountered in spill prevention. A representative key to first order classification (Appendix C) was devised to demonstrate the format and for use with the photointerpretation test later described. Development of the key beyond the first order of classification and development of illustrative and collateral material for such a comprehensive key were beyond the scope of this project.

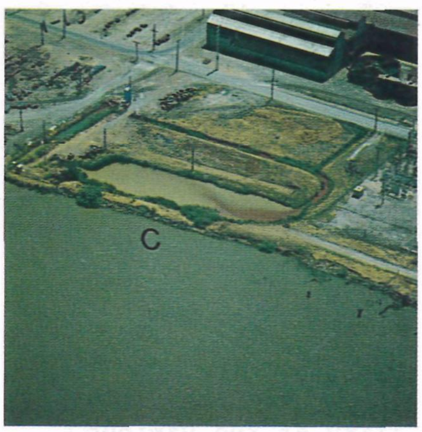
The results presented for Figures 12 through 42 are illustrative of the photointerpretation performed on the imagery acquired during this project. This interpretation included evaluation of the utility of the various film/filter combinations at each of the various scales imaged, for the purpose of detecting the features of interest in spill prevention surveillance; Table 6 graphically presents these results. Highlighted entries represent combinations of scale and film/filter, wherein a particular feature can be readily identified and classified. In the



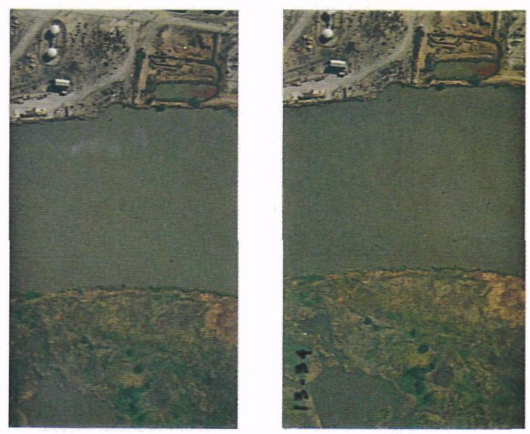
1/40,000, Color IR/12, July 27, 1971



1/10,000, Color/1A, September 9, 1971

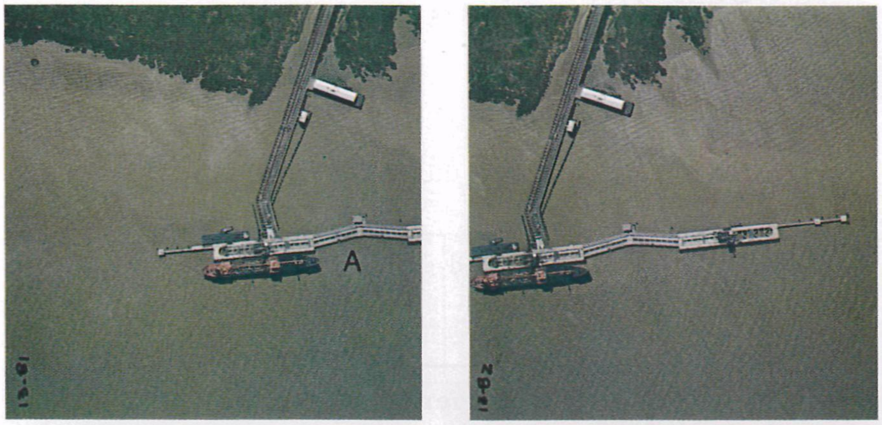


Color/1A, July 17, 1971

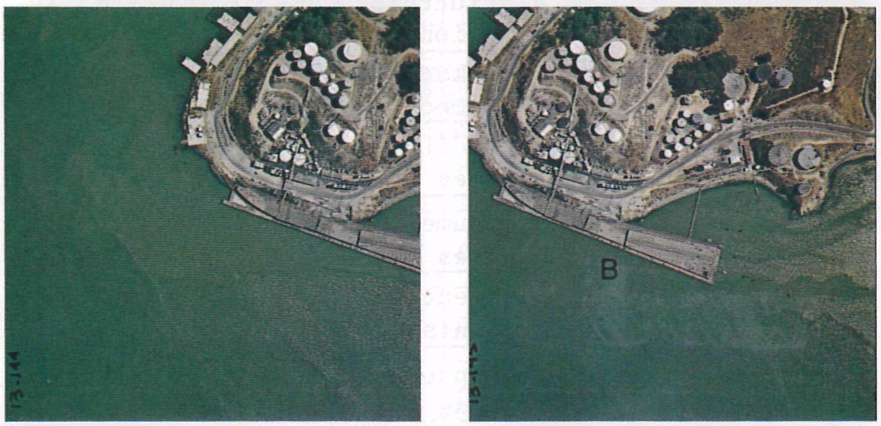


1/10,000, Color/1A, September 8, 1971

FIGURE 41. STEEL MILL AND WASTE, PITTSBURG TEST AREA.



1/10,000, Martinez Test Area, Color/1A, September 9, 1971



1/10,000, Richmond Test Area, Color/1A, September 9, 1971

1/5,000, Avon Test Area, Color/1A, August 8, 1971

FIGURE 42. OIL SHIPMENT FACILITIES.

Table 6(a). Results of Photointerpretation

X - Detectable
0 - Undetectable
N - Not recommended
E - No example

		COLOR IR/12					
		1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500
1. BULK STORAGE	number of tanks	X-	X	X	X	X	X
	material stored in tanks	0	0	0	0	0	0
	structural condition of tanks	0	0	0	0	0	0
	leaks or seepage around tank area	0	X-	X	X	X	X
DIKES	condition of dikes	0	0	X-	X	X	X
	volume behind dikes	0	0	0	X	X	X
	potential failure points	0	0	0	X	X	X
	compacted or loose soil banks	0	0	0	X-	X	X
DRAINAGE	drainage piping thru dikes	0	0	0	X	X	X
	valve condition	0	0	0	0	0	0
PIPING	above or below ground	0	0	0	X	X	X
	condition of pipes	0	0	0	0	0	0
	trash and debris in dikes	0	0	X-	X	X	X
2. INDUSTRIAL WASTE	type of material	0	0	X-	X-	X-	X-
	volume of layover or pile	0	0	X-	X	X	X
	detention time inflow rate	0	0	0	0	0	0

Table 6(a). (cont.)

COLOR/1A						INFRARED/89B						PAN/47B					
1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500	1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500	1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500
X-	X	X	X	X	X	0	X-	X-	X	X	X	N	N	X	X	X	X
0	0	0	0	0	0	0	0	0	0	0	0	N	N	0	0	0	0
0	0	0	0	0	X-	0	0	0	0	0	0	N	N	0	0	0	0
X-	X	X	X	X	X	X-	X-	X	X	X	X	N	N	X-	X	X	X
0	0	X-	X	X	X	0	0	0	0	X-	X	N	N	X-	X-	X-	X-
0	0	0	X	X	X	0	0	0	0	X-	X	N	N	X-	X-	X-	X
0	0	0	X	X	X	0	0	0	0	0	0	N	N	0	0	0	0
0	0	0	X-	X	X	0	0	0	0	0	0	N	N	0	0	0	0
0	X-	X	X	X	X	0	0	0	X-	X	X	N	N	0	X	X	X
0	0	0	0	0	0	0	0	0	0	0	0	N	N	0	0	0	0
0	0	X-	X	X	X	0	0	0	X-	X-	X	N	N	0	X	X	X
0	0	0	0	0	X-	0	0	0	0	0	0	N	N	0	0	0	0
0	X-	X	X	X	X	0	0	0	X-	X-	X	N	N	0	X-	X	X
0	0	X-	X	X	X	0	0	0	0	0	0	N	N	0	0	0	0
0	0	0	X	X	X	0	0	0	0	X-	X	N	N	0	X-	X	X
0	0	0	0	0	0	0	0	0	0	0	0	N	N	0	0	0	0

Table 6(b). Results of Photointerpretation

X - Detectable
0 - Undetectable
N - Not recommended
E - No example

		COLOR IR/12					
		1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500
	source of waste product	X-	X	X	X	X	X
DIKE CONDITION	compacted or loose soil	0	0	0	X-	X	X
	potential failure point	0	0	0	X	X	X
	leaks	0	X-	X-	X	X	X
EFFLUENT LOCATION	discharge point to river	0	X-	X	X	X	X
3. OPEN STORAGE PILES	volume of material	0	0	0	X-	X	X
	type of material	0	0	0	0	X-	X-
	drainage pattern	X-	X	X	X	X	X
	observed drainage in waterway	0	X	X	X	X	X
4. PIPELINES OVER WATERWAYS	condition of lines	0	0	0	X-	X-	X-
	condition of holding structure	0	0	0	X-	X-	X-
	leaks	0	0	X-	X	X	X
5. RAILROADS AND TANK CARS	type of material	0	0	0	0	0	0
	spillage in transfer	0	0	X-	X	X	X
6. MARINE TERMINALS	transfer operations	0	X	X	X	X	X
	oil in harbor	E	X-	X	X	X	X

Table 6(b). (cont.)

COLOR/ 1A						INFRARED/ 89B						PAN/47B					
1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500	1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500	1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500
X-	X	X	X	X	X	0	0	X-	X	X	X	N	N	X-	X	X	X
0	0	0	X	X	X	0	0	0	0	0	0	N	N	0	0	0	0
0	0	0	X	X	X	0	0	0	0	0	0	N	N	0	0	0	0
0	X	X	X	X	X	0	0	X-	X	X	X	N	N	X-	X	X	X
0	X-	X	X	X	X	0	0	0	X-	X-	X	N	N	X-	X	X	X
0	0	0	X	X	X	0	0	0	X-	X-	X	N	N	0	0	X-	X
0	X-	X-	X	X	X	0	0	0	0	0	0	N	N	0	0	0	0
0	X-	X	X	X	X	0	X	X	X	X	X	N	N	X-	X	X	X
X-	X	X	X	X	X	0	0	0	0	0	0	N	N	X-	X-	X-	X-
0	0	0	0	X-	X-	0	0	0	0	0	0	N	N	0	0	0	0
0	0	0	0	X-	X-	0	0	0	0	0	0	N	N	0	0	0	0
X-	X	X	X	X	X	0	0	0	X	X	X	N	N	0	X-	X	X
0	0	0	0	0	0	0	0	0	0	0	0	N	N	0	0	0	0
0	X-	X	X	X	X	0	0	X-	X	X	X	N	N	0	0	X	X
X-	X	X	X	X	X	0	0	0	X	X	X	N	N	X-	X-	X	X
E	E	E	X	X	X	0	0	0	0	0		N	N	X	X	X	X

Table 6(c). Results of Photointerpretation

X - Detectable
0 - Undetectable
N - Not recommended
E - No example

		COLOR IR/12					
		1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500
7. REFINERIES AND PROCESSING PLANTS	transfer	0	0	X-	X-	X	X
	location of raw materials - crude	0	0	0	0	0	0
	type of raw material	0	0	0	0	X-	X
	drainage pattern	X-	X	X	X	X	X
	condition of storage tanks	0	0	0	0	0	0
	condition of pipelines	0	0	0	0	0	0
	location of effluents	X-	X	X	X	X	X
	water condition near outfall	0	X-	X-	X	X	X
8. CLASSIFICATION SCHEME	able to classify	X	X	X	X	X	X
9. PROTECTIVE FACILITIES	fences along lines	0	0	0	X-	X	X
	railroad car barricades	0	0	0	X	X	X
	dikes present or absent	0	0	X-	X	X	X
	tracing pipeline routes	0	X-	X-	X	X	X

Table 6(c). (cont.)

COLOR/1A						INFRARED/89B						PAN/47B					
1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500	1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500	1/80,000	1/40,000	1/20,000	1/10,000	1/5,000	1/2,500
0	X-	X	X	X	X	0	0	X	X	X	X	N	N	0	X-	X	X
0	0	0	0	0	0	0	0	0	0	0	0	N	N	0	0	0	0
0	0	X-	X	X	X	0	0	0	0	0	0	N	N	0	0	0	0
0	X-	X	X	X	X	0	0	X	X	X	X	N	N	X-	X	X	X
0	0	0	0	0	X-	0	0	0	0	0	0	N	N	0	0	0	0
0	0	0	0	0	X-	0	0	0	0	0	0	N	N	0	0	0	0
X-	X	X	X	X	X	0	0	X-	X-	X	X	N	N	X-	X-	X-	X
X-	X	X	X	X	X	0	0	0	0	0	0	N	X-	X-	X-	X-	X-
X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
0	0	0	X	X	X	0	0	0	0	X-	X	N	N	0	X-	X-	[illegible]
0	0	X	X	X	X	0	0	X-	X	X	X	N	N	X-	X	X	X
0	0	X-	X	X	X	0	0	0	0	X-	X	N	N	0	0	X-	X
0	X-	X	X	X	X	0	X-	X	X	X	X	N	N	X-	X-	X	X

case of panchromatic film with Wratten 47B filter, many applications are not recommended, as this film/filter combination is extremely sensitive to degradation of information content by intervening atmospheric haze.

The features which are listed in Table 6 as undetectable (0) for all film/filter combinations and all scales had to be identified through a ground visit to the site. Those features which were marginally detectable (X-) with a given film/filter combination at a given scale required supporting ground data for complete identification. The following list includes features which required a ground visit for proper identification:

- Material stored in tanks
- Structural condition of tanks
- Condition of control valves in pipelines or tanks
- Condition of pipes and holding structures of elevated pipelines
- Inflow rate and detention time of industrial waste
- Identity of material in railroad tank cars

Assistance in accomplishing these identifications was obtained by interviews with key personnel at the power plants in Pittsburg and at Hunters Point, the refineries at Avon and Martinez, and the chemical plant in Berkeley, among others.

Qualified photointerpreters not associated with the project were given a test, using project imagery and the photointerpretation key in order to arrive at an unbiased comparison of the findings. Results of the test substantiated the conclusions previously drawn and are presented in Appendix D.

SECTION VI

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Project Manager for this study was Dr. Paul M. Maughan. Dr. Robin I. Welch served as Principal Investigator, and Dr. Allan D. Marmelstein was Co-Investigator. Other key EarthSat participants included Dr. Robert N. Colwell and Mr. O. Ray Temple.

SECTION VII

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SECTION VIII

GLOSSARY

Collateral Data - All sources other than the imagery being interpreted which contribute to the body of data on a given target.

Displacement, Radial - Dimensional changes in photography caused by lens characteristics and relief differences between object location and the point on the imagery corresponding to the ground position vertically beneath the camera (nadir).

Format - The actual size of the negative or positive transparency on which an image is produced.

Ground Truth - Actual conditions, identifications, sites, and other information on objects of interest in image interpretation.

Imagery - Representations of objects produced electronically or optically on film, electronic display devices, or other media.

Interpreter, Image - An individual trained in the process of detecting, identifying, analyzing, and accurately locating, with respect to a known reference, objects and activities portrayed on imagery, as well as determining the implications of those objects and activities. The term is replacing the older designation "photointerpreter" or PI, as non-photographic imaging systems come into widespread use.

Key, Image Interpretation - An illustrated reference material designed to aid image interpreters in the rapid, accurate identification of an object from the study of its image.

Magnifier, Photointerpreter's or Tube - Measuring device consisting of a transparent tube, with a lens element at one end and a reticle at the other, used to measure distances of up to about one inch on imagery.

Micrometer - Unit of length equivalent to 10^{-6} meters. Formerly called micron. Commonly used in discussion of the infrared portion of the spectrum, wavelengths from 0.70 micrometers (700 nanometers) to 1,000 micrometers.

Mensuration - Measurement of images on film.

Monoscopy - Viewing or interpretation of a single image, therefore not achieving a three-dimensional effect.

Mosaic - An assemblage of overlapping aerial photographs which have been matched to form a continuous photographic representation.

Nanometer - Unit of length equivalent to 10^{-9} meters and to 10^{-3} micrometers. Formerly called millimicron. Commonly used when working in the visible portion of the spectrum; about 400-700 nanometers wavelength.

Oblique Aerial Photograph - Photograph taken with the camera axis intentionally directed between the horizontal and the vertical. A photograph is generally considered oblique if the camera is tilted more than 3° from the vertical. Commonly referred to as an oblique.

Parallax - The apparent displacement of the position of a body with respect to a reference point or system, caused by a shift in the point of observation.

Photogrammetry - The art of obtaining reliable ground distance measurements from photography.

Powerpod (Zoom Stereoscope) - Main body of a zoom stereoscope which contains both the variable magnification (zoom) mechanism and the separate optical paths for stereoscopic viewing. Resolution of the instrument is determined by quality of the powerpod.

Principle Point - Point on a frame of imagery corresponding to the nadir, or the ground point vertically below the aircraft at the instant of exposure on vertical photography.

Rhomboid (Zoom Stereoscope) - Opto-mechanical arms which rotate in a horizontal plane about the powerpod to provide image separation for stereoscopic viewing.

Scale - The ratio of a measured distance on a map, photography, or mosaic to the corresponding distance on the ground. As the denominator of the ratio increases, the scale is said to become smaller:

Large - 1/12,000 or less
Medium - 1/12,000 to 1/25,000
Small - over 1/25,000

Scale, Photointerpreter's - A rule, usually six to ten inches long, graduated in .001 feet and/or 0.1 millimeters, used for making long, but precise, measurements on imagery.

Spectrum, Photographic - The segment of the electromagnetic spectrum between about 360 nanometers and 900 nanometers.

Stereogram - Two or more photographs with sufficient overlap and consequent duplication of detail to make possible stereoscopic examination of objects or areas common to adjacent frames.

Stereographic Coverage - Photographic coverage with overlapping aerial photographs to provide a three-dimensional presentation of the picture; a 53% overlap is generally regarded as minimum.

Stereoscope - A binocular optical instrument for assisting the observer to view two properly oriented photographs to obtain the mental impression of a three-dimensional model.

Stereoscope, Mirror, or Prism - Viewing device which uses prisms or diagonal mirrors to achieve greater image separation than simple stereoscopes for viewing large-format imagery.

Stereoscope, Simple or Pocket - Viewing device usually having only two simple lenses and fixed magnification best suited for field work or noncritical investigation.

Stereoscope, Zoom - Complex stereoscope for use with transparencies and light tables, featuring continuously variable magnification, high optical resolution, interchangeable lenses, and variable image separation.

Stereoscopy - Production and use of three-dimensional effects in interpretation of imagery.

Wedge, Parallax - Measuring device for height determination from stereoscopic pairs of photographs. It consists of two slightly graduated lines printed on a transparent template, which can be stereoscopically fused into a single line for making parallax measurements.

SECTION IX

APPENDICES

APPENDIX A

Representative Costs for Aerial Surveillance

The costs associated with various remote sensing missions, when contracted with commercial aerial survey firms, vary depending upon scale, weather contingencies, size of area covered, time constraints, distance to target area from the base of operations, and maximum flying height required.

Color and black-and-white vertical photographic coverage can be flown commercially for the approximate costs listed below:

Average Costs for Aerial Photographic Coverage		
Scale	Black-and-White cost per sq. mi. (dollars)	Color (positive transparency) cost per sq. mi. (dollars)
1/5,000	18-20	20-25
1/10,000	6-8	8-10
1/20,000	2-3	3-4
1/40,000	.8-1.0	1-2

These costs assume use of a 9-inch film format in an operational system. Color positive transparencies in 70mm format, which will be required for oblique, and possibly short-strip vertical photography, cost $3 to $4 per frame.

Any photo acquisition system must be accompanied by a well-organized and viable image interpretation capability. Suitable viewing, projection and measuring devices, and comprehensive reference materials must also be available.

Using the equipment described in section IV, and 1/40,000 scale color infrared photographs, a photointerpreter can classify industrial facilities and major spill threats at a rate of about 3 stereo pairs per hour depending on the density of industrial features and the number of potential spill threats. He can perform detailed interpretations on 1/5,000 scale color photographs, listing and delineating specific data on spill threats, such as their areas, distances from waterways, numbers of storage tanks, and associated environmental characteristics. It is difficult, however, to define an average output rate because of the variability in features of interest, need for mensuration, and the proximity to drainage features leading to waterways. However, the rate involved is estimated to be about two stereo pairs per hour. These average hourly outputs can be used to compute costs based on the salary level of the photointerpreter. We feel a salary level of $10,000 to $12,000 per year (equivalent GS-11) is representative.

APPENDIX B

Photointerpretation Selection and Interpretation Procedures

A person selected for imagery interpretation training should possess the capacity to extract bits of information from imagery and assemble those bits to arrive at an identification, as well as being able to deduce from image-derived and collateral data the significance of objects and facilities. The interpreter must be able to make judgements and identifications with a high degree of accuracy and to his own satisfaction, as he may have to defend his interpretation. The imagery interpreter is the only link between the raw data of limited direct use and a finished intelligence product. Furthermore, he should have good color vision and be free of eye disease or uncorrectable vision defects, have the ability to see three-dimensional images on stereoscopic pairs of photographs, and have the mental attitude and capacity to perform repetitive tasks during prolonged periods of time, as necessary, to develop useful information from photographic images and supporting data.

Prospective interpreters must be trained in photography, image interpretation in one or more disciplines, photogrammetry, systems for remote sensing, and elementary physics. The more extensive an interpreter's background, the more readily he may adapt to a multidisciplinary field such as spill prevention.

Field work is advantageous for interpreters in order that they become familiar with the appearance and function of ground activity. The collective body of collateral data or experience will directly influence the depth and accuracy of analysis. The photointerpreter should also be involved in specifying mission parameters and in preparing flight maps to optimize the factors under his control. He should obtain reference materials to guide his interpretation efforts, such as photointerpretation keys, ground photography, reports, and other descriptions of the target conditions and associations which he will be asked to evaluate.

Arrangements for film processing and editing are generally made by the service providing the aerial photography. Ground checking activities are usually planned ahead of aircraft flights, although, in the spill prevention system defined here, the final step would be a ground check of those areas where spill threats had been identified. Thus, no prior planning for ground checking would be needed except, perhaps, to define the format of materials needed for ground checking efforts.

When small scale photographs are received, the photointerpretation team immediately identifies the map area imaged by each photography. Each team member would then analyze photographs assigned to him. He would systematically scan each stereoscopic pair in a convenient fashion -- left to right working from top to bottom -- until all areas of the photograph have been viewed. He would then proceed to the next pair of photographs and so forth.

A team leader generally functions to coordinate interpretation tasks, assigning individuals to work on jobs most suited to their abilities and maintaining periodic checks on interpreter performance.

Several methods for delineating features of interest and marking them with an identifying code are commonly used. One method is to write directly on the film, either temporarily with grease pencil or permanently with a marking pen using India ink or a similar lacquer type ink. Another method is to indicate on a frosted acetate overlay, in either pen or pencil, the data of interest. The method chosen depends largely on the data reproduction and distribution requirements for the finished product.
The method used to mark a feature is usually to encircle (delineate) the boundary, enclosing the feature or area, and to write an identifying symbol or code adjacent to it in a way that does not obscure useful image components.

Data sheets should be prepared to provide a common format for entries pertaining to target data. These forms can be developed to be compatible with the standard practices of the data user.

The practicing photointerpreter should periodically compare his results with those of other interpreters, and with reference materials, to insure consistency of his interpretation. It is usually advisable to have more than one interpreter analyze photos of vital areas to minimize errors.

APPENDIX C

First Order Photointerpretation Key

A photointerpretation key for spill threat analysis would be unique, since it would combine elements of municipal, industrial, and agricultural activity analysis. Although comprehensive keys to each of these land uses have been developed by the military, few seem to be readily available for civilian application. As far as is known by the project staff, nothing comparable to a spill prevention key exists other than the preliminary key presented here.

FIRST ORDER PHOTOINTERPRETATION KEY FOR FACILITIES ASSOCIATED WITH POTENTIAL SPILL SOURCES

1. Area contains railroads, highways, pipelines and/or docks with associated pumps, tanks, and holding areas .... Transport facilities

1. Area contains few, if any, of the above features .... See #2

    2. Area contains large open pits, large piles of bulk material, and a conspicuous network of roads leading into pit and storage pile areas .... Open pit mining or borrow pit facilities

    2. Area contains few, if any, of the above features .... See #3

3. Area contains numerous storage tanks usually close to buildings and structures with tall vent stacks, numerous pipelines, storage reservoirs, slag and waste piles, cooling towers and/or loading docks.... .... Refinery and processing facilities

3. Area contains few, if any, of the above features .... See #4

    4. Area contains large buildings with numerous vents and stacks on rooftop, storage yards for finished projects, facilities for unloading from trucks, trains, or ships, and large parking lots for employees' vehicles....Manufacturing and assembly facilities

    4. Area contains few, if any, of the above features .... See #5

5. Area contains a series of rectangular or circular ponds with stirring or aerating mechanisms visible; large settling basin(s) visible; piles, bales or containers of waste paper, scrap steel, wrecked autos, ships, rail cars, or other salvageable material also visible .... Waste treatment, recycling, and disposal facilities

5. Area contains few, if any, of the above features .... See #6

    6. Area consists of either cleared land, with leveled or terraced

hills and filled gulleys, or bare soil and rocks along shoreline or in spits with steeply sloping banks .... Land development and filling facilities

6. Area contains few, if any, of the above features .... See #7

7. Area contains buildings with tall vent stacks, numerous transformers and powerlines, liquid holding basins and/or fuel storage tanks..... .... Fossil fuel power generation facilities

7. Area contains few, if any, of the above features .... See #8

8. Area contains either even rows of trees or plants with clearly defined boundaries or a continuous cover of vegetation of uniform density and color with clearly defined boundaries, a network of access roads and/or irrigation facilities (canals, reservoirs, pumps, pipes, and sprinkler systems)..... Agriculture facilities

8. Area contains few, if any, of the above features .... See #9

9. Area contains large buildings or other nonresidential facilities under construction on cleared or filled land. Could be part of an existing industrial complex .... Construction facilities

9. Area contains few, if any, of the above features .... See #10

10. Area consists of tree covered or recently cleared parcels with road networks and log storage piles usually visible .... Forestry facilities

10. Area contains few, if any, of the above features .... See #11

11. Area contains large parcels that are devoted to stockpiles; buildings separated by driveways, loading docks and/or rail sidings; or large paved areas usually present, but no evidence of processing or manufacturing .... Storage area facilities

11. Area contains few, if any, of the above features .... Non-polluting facilities and areas

APPENDIX D

Photointerpretation Test

The photointerpretation test was designed to provide a basis for a comparison of findings of the project staff with regard to interpretability of the various film-filter-scale combinations. Twelve interpreters not familiar with the project or test areas were tested, and the results are presented here. Test results substantiated the findings reported in Table 6. The questionnaire concludes this appendix.

RESULTS OF PHOTOINTERPRETATION TEST

Dates Tests were Administered: 11/22/71 - 11/23/71

Number of Tests Administered: 12

Responses:	Number of People Answering	Percentage of Total
Question 1-(a)		
Refining and Processing Installations:	11	92%
Waste lagoons and cooling ponds:	1	8%
All other responses:	0	0%
Total	12	100%
Question 1-(b)		
Storage tanks:	12	100%
All other responses:	0	0%
Total	12	100%
Question 1-(c)		
Refining and processing installations:	11	92%
Storage tanks:	1	8%
All other responses:	0	0%
Total	12	100%
Question 1-(d)		
Yes:	10	83%

Responses:	Number of People Answering	Percentage of Total
Question 1-(d) (cont.)		
No:	2	17%
Total	12	100%

(Note: For all "No" answers, the following responses were given regarding what subjects felt the correct activity was:

1 Waste Treatment and Recycling and Disposal
1 Refining and Processing)

Question 2-(a): (Pipeline Plotting)		
Film Type: PAN 47-B		
1/80,000	0	0%
1/40,000	1	8.33%
1/20,000	6	50.0 %
1/10,000	3	25.0 %
1/5,000	2	16.67%
1/2,500	0	0%
Total	12	100. 0%
Film Type: IR 89-B		
1/80,000	0	0%
1/40,000	2	16.67%
1/20,000	5	41.67%
1/5,000	3	25. 0%
1/2,500	1	8.33%
	1	8.33%
Total	12	100. 0%
Film Type: Color		
1/80,000 (this scale not given on this film type)	0	0%
1/40,000 (this scale not given on this film type)	0	0%
1/20,000	9	75.0%
1/10,000	3	25.0%
1/5,000	0	0%
1/2,500	0	0%

Responses:	Number of People Answering	Percentage of Total
<u>Question 2-(a)</u> (cont.)		
Total	12	100.0%
Film Type: Color IR		
1/80,000	1	8.33%
1/40,000	3	25. 0%
1/20,000	4	33.33%
1/10,000	3	25. 0%
1/5,000	1	8.33%
1/2,500	0	0%
Total	12	100. 0%
<u>Question 2-(b)</u>: (Guard Fence Detection)		
Film Type: PAN 47-B		
1/80,000	0	0%
1/40,000	1	8.33%
1/20,000	2	16.67%
1/10,000	4	33.33%
1/5,000	1	8.33%
1/2,500	4	33.33%
Total	12	100. 0%
Film Type: IR 89-B		
1/80,000	1	8.33%
1/40,000	0	0%
1/20,000	1	8.33%
1/10,000	4	33.33%
1/5,000	1	8.33%
1/2,500	5	41.67%
Total	12	100. 0%
Film Type: Color		
1/80,000 (this scale not given on this film type)	0	0%
1/40,000 (this scale not given on this film type)	0	0%
1/20,000	3	25.0%
1/10,000	6	50.0%
1/5,000	3	25.0%

Responses:		Number of People Answering	Percentage of Total
Question 2-(b) (cont.)			
1/2,500		0	0%
	Total	12	100. 0%
Film Type: Color IR			
1/80,000		1	8.33%
1/40,000		1	8.33%
1/20,000		2	16.67%
1/10,000		2	16.67%
1/5,000		3	25. 0%
1/2,500		3	25. 0%
	Total	12	100. 0%

RESPONSE SHEET FOR EPA SPILL PREVENTION SYSTEM

1. Note on the 1/80,000 scale Pan 47B photos the installation delineated on the frames. Identify each half of the installation from the following list. (Check only one box in each column):

a. North	b. South	
☐	☐	Slag piles
☐	☐	Waste lagoons and cooling ponds
☐	☐	Terminals
☐	☐	Storage tanks
☐	☐	Pumping stations, pipelines and outfalls
☐	☐	Refining and processing installations
☐	☐	Slaughterhouses
☐	☐	Livestock pens

c. Identify the entire complex from the following list. (Check one box):

- ☐ Mining
- ☐ Transport
- ☐ Storage
- ☐ Manufacturing and assembly
- ☐ Refining and Processing
- ☐ Waste treatment and recycling and disposal
- ☐ Land development and filling
- ☐ Forestry
- ☐ Agriculture
- ☐ Construction
- ☐ Power generation

d. Verify your interpretation on the color IR photos. Is your interpretation the same? __________ Yes or No. If not, what is the activity carried on at the complex?

2. It is obvious that in a facility such as you are viewing a great many pipelines exist interconnecting the various components.

a. At what scale can you begin to follow pipeline routes? Work from 1/80,000, 1/40,000, 1/20,000, etc., for each film before proceeding.

	Pan 47B	IR 89B	Color	Color IR
1/80,000				
1/40,000				
1/20,000				
1/10,000				
1/5,000				
1/2,500				

b. At what scale can you see guard rails or fences protecting the pipelines from vehicle traffic along main roads?

	Pan 47B	IR 89B	Color	Color IR
1/80,000				
1/40,000				
1/20,000				
1/10,000				
1/5,000				
1/2,500				

1 Accession Number	2 Subject Field & Group	SELECTED WATER RESOURCES ABSTRACTS
	05B	INPUT TRANSACTION FORM

5 *Organization*

Earth Satellite Corporation
Washington, D. C.

6 *Title*

A Feasibility Demonstration of An Aerial Surveillance Spill Prevention System

10 *Author(s)*

Welch, Robin I.
Marmelstein, Allan D.
Maughan, Paul M.

16 *Project Designation*

EPA, ORM Contract No. 68-01-0145

21 *Note*

22 *Citation*

23 *Descriptors (Starred First)*

*Water pollution sources, oil, chemicals, remote sensing, aerial sensing, photography, photogrammetry

25 *Identifiers (Starred First)*

*Multispectral photography, thermal imagery, color photography, photointerpretation, hazardous materials

27 *Abstract*

Acquisition and interpretation of multispectral aerial photography and thermal infrared imagery was performed to evaluate remote sensing applications to spill prevention surveillance. The San Francisco Bay area was used as a test site, with major sub-areas delineated which contained facilities and activities which might lead to spills of oil and other hazardous substances into waterways.

Results demonstrated that high quality, small scale (1/40,000 to 1/60,000) color infrared photography can be used for regional surveillance leading to classification of land use into areas where potential spill sources exist. High quality, large scale (1/5,000 to 1/10,000) color aerial photography can be used for localized delineation of potential spill sources. Localized surveillance should be supported by low angle oblique telephotography and limited ground surveillance.

Recommendations are given for an operational spill surveillance system using multi-scale aerial photography obtained on a 9-inch film format. Use of thermal infrared imagery is not indicated at this time, as additional information acquired is minimal compared to resources required for its acquisition.

Abstractor	Institution
Allan D. Marmelstein	Earth Satellite Corporation

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